

For Reference

NOT TO BE TAKEN FROM THIS ROOM

Ex LIBRIS
UNIVERSITATIS
ALBERTAENSIS





Digitized by the Internet Archive
in 2019 with funding from
University of Alberta Libraries

<https://archive.org/details/Peterman1962>

1962 (F)
9D

THE UNIVERSITY OF ALBERTA

PRECAMBRIAN BASEMENT OF SASKATCHEWAN AND MANITOBA

BY

ZELL EDWIN PETERMAN, Geol.Eng., M.S.

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF GEOLOGY

EDMONTON, ALBERTA

JUNE, 1962

ABSTRACT

The covered Precambrian of Saskatchewan and Manitoba forms a large part of the basement of the western Canada sedimentary basin. K-Ar age determinations of 45 samples indicate that the basement of Saskatchewan was affected by the Hudsonian orogeny between about 1.65 and 1.85 b.y. ago. The Superior-Churchill boundary as defined by K-Ar dating extends from the Nelson River gneissic zone southwest into Saskatchewan and thence into north-central North Dakota. The Nelson River gravity low and its extension into North Dakota is in agreement with the boundary as determined by the K-Ar dates.

The widespread effects of the Hudsonian orogeny on the older Superior craton are indicated by several intermediate K-Ar values. Events later than the main Hudsonian orogeny have had local effects on the Churchill basement in Saskatchewan.

Dates older than 1.83 b.y. have not been determined either from rocks of the exposed shield or from the basement within the Churchill province; however, comparison with a similar geologic setting near the boundary of the Slave province in the Northwest Territories suggests that older rocks probably do exist near the boundary of the Superior province. Future Rb-Sr and U-Pb dating applied to rocks from the exposed and covered shield may reveal further complexities in the geologic history of the region.

Petrographic data obtained on core samples from 43 wells indicate that the basement is composed mainly of silicic to intermediate plutonic rocks where metamorphic rocks exceed those of igneous origin. Alkalic, epizonal plutonic, and volcanic rocks are widespread in southwestern Saskatchewan and metasedimentary and metavolcanic rocks are prominent in east-central Saskatchewan, whereas silicic to intermediate igneous and metamorphic plutonic rocks underlie west-central Saskatchewan.

Reactivation along Precambrian trends has controlled younger structures in the Cordilleran foreland region of Montana and North Dakota, but in Saskatchewan and Manitoba opinions vary as to the cause of structures in the Phanerozoic sedimentary rocks.

ACKNOWLEDGEMENTS

The writer is especially indebted to Dr. R. A. Burwash who suggested the thesis problem, collected the basement samples, and supervised the research leading to the completion of this thesis. The writer gratefully acknowledges the efforts of Dr. H. Baadsgaard in conjunction with the dating aspect of this thesis. Drs. F. A. Campbell, G. L. Cumming, R. E. Folinsbee, and J. D. Godfrey critically reviewed the manuscript.

Thanks are due to the following individuals for furnishing samples: G. S. Barry, Manitoba Mines Branch; J. P. Gries, South Dakota School of Mines; E. Leith, University of Manitoba; J. B. Mawdsley, University of Saskatchewan; D. H. Rousell, Manitoba Mines Branch; and D. L. Surjik, Saskatchewan Department of Mineral Resources. Acknowledgement is made to the various oil companies indicated in the names of wells from which basement samples were studied.

Financial support was obtained from a grant to Dr. R. A. Burwash from the National Research Council of Canada. The University of Alberta Research Fund supported a collecting trip to Lynn Lake and Flin Flon, Manitoba. The writer is grateful for the teaching assistantships awarded him during the 1959-1960 and 1960-1961 terms by the Department of Geology.

TABLE OF CONTENTS

	Page
Abstract -----	i
Acknowledgements -----	iii
Introduction -----	1
General Statement -----	1
Location and Size of Area -----	1
Sample Availability and Distribution -----	3
Methods -----	4
Previous Work -----	4
Regional Setting and General Geology -----	9
Division of the Canadian Shield into Geologic Provinces -----	9
Geology of Shield Areas Adjacent to the Main Area of Study -----	13
Area I -----	15
Southern District of Keewatin -----	17
Southeastern District of Mackenzie -----	18
Northeastern Alberta and Northern Saskatchewan -----	21
Tazin group -----	23
Post-Tazin--Pre-Martin Intrusions -----	26
Martin formation -----	27
Athabasca series -----	28
Post-Athabasca intrusions -----	28
Regional Correlations and Dates -----	28
Age of the Tazin group -----	30
Age of the Martin formation -----	33
Age of the Nonacho group -----	34
Age of the Hurwitz group -----	35
Age of the Dubawnt group -----	35
Age of the Athabasca formation -----	35
Area II -----	38
Wollaston Lake -----	39
Reindeer Lake-Spalding Lake -----	40
Foster Lake-Oliver Lake -----	40
Lac la Ronge and Ile 'a la Crosse -----	42
Pelican Narrows (west half) -----	44
Porter Lake-Haultain River -----	45
Weitzel Lake-Brustad River-Upper Clearwater River Firebag River -----	45
Summary, Regional Correlations and Dates -----	46
Area III -----	50
Northern Manitoba -----	50
Lynn Lake-Flin Flon -----	53
Ages and Correlations -----	60
Area IV (Thicket Portage area) -----	68
Area V -----	77
Gods Lake-Knee Lake-Oxford Lake -----	78
Island Lake area -----	80
Cross Lake area -----	82

	Page
Area VI (Southeastern Manitoba) -----	88
Area VII (Minnesota) -----	92
Area VIII (Little Rocky Mountains) -----	96
Area IX (Little Belt Mountains) -----	99
Area X (Beartooth Mountains) -----	101
Major Features of the Precambrian Basement Surface -----	104
Montana -----	106
Regional Setting -----	106
Basement Features -----	108
North and South Dakota -----	112
Regional Setting -----	112
Basement Features -----	113
Manitoba -----	115
Regional Setting -----	115
Basement Features -----	116
Saskatchewan -----	117
Regional Setting -----	117
Basement Features -----	118
Geophysical Data -----	122
Summary -----	126
Alberta -----	126
Regional Setting -----	126
Basement Features -----	128
Geophysical Data -----	131
Summary -----	131
Petrology -----	132
Petrography -----	132
General Statement -----	132
Specific Gravity Determinations -----	136
Igneous Rocks -----	137
Southwestern Saskatchewan -----	139
West-Central Saskatchewan -----	141
Igneous Rocks from Other Areas -----	142
Metamorphic Rocks -----	144
Interpretive Petrology -----	150
General Statement -----	150
Areal Distribution and Abundances of Rock Types -----	150
Comparisons with Adjacent Shield Areas -----	152
Radioactive Dating -----	161
Introduction -----	161
Methods -----	162
General Discussion -----	162
K-Ar Geochronometer -----	162
Rb-Sr Geochronometer -----	164
Minerals Dated and Separation Techniques -----	166
Biotite -----	166
Hornblende and Pyroxene -----	168
Muscovite -----	170
Potassium Feldspars -----	170

Potassium Determinations -----	171
Gravimetric -----	171
Flame Photometric -----	172
Argon Determinations -----	172
Extraction -----	172
Isotopic Measurements -----	175
Age Calculations -----	176
Evaluation of Methods and Minerals -----	181
K-Ar Method -----	181
Analytical Precision -----	181
Geological Factors -----	185
Rb-Sr Method -----	189
Analytical Precision -----	189
Geological Factors -----	190
Dating Results -----	192
Basement Samples -----	192
Outcrop Samples -----	192
Dates of Co-existing Biotite and Hornblende -----	192
Dates on Impure Hornblende and Pyroxene Separates -----	196
Dates on Pyroxenes -----	199
Rb-Sr Dates -----	200
Summary and Conclusions -----	203
Churchill-Superior Boundary -----	203
Basement Extents of Churchill and Superior Provinces -----	206
Basement Composition and Structure -----	208
Relation of Dates to Rock Types -----	211
Precambrian History -----	214
References Cited -----	219
Appendix A, Photomicrographs of Basement and Dated Samples -----	234
Appendix B, Petrographic Descriptions -----	244
Basement Samples -----	244
Dated Outcrop Samples -----	292
Appendix C, Basic Data for Map Point Counts -----	312

LIST OF FIGURES, TABLES AND PLATES

Page

Figures

Figure 1.	Index Map -----	2
2.	Geologic Provinces of the Canadian Shield -----	12
3.	Division of Part of the Western Canadian Shield and Areas Discussed -----	16
4.	Geology of the Clut-Astrolabe Lakes Area -----	32
5.	Geology of the Rusty Lake Area -----	63
6.	Geology of the Pool Lake Area -----	65
7.	Geology of the Flin Flon Area-----	66
8.	Geology of the Thicket Portage and Cross Lakes Area -----	75
9.	Geology of Gods Lake -----	87
10.	Geology of the Little Rocky Mountains -----	98
11.	Geology of the Little Belt Mountains -----	100
12.	Structure Contour Map of the Precambrian Surface of the Western Canada Sedimentary Basin -----(in pocket)	
13.	Generalized Geophysical and Basement Structural Map -----(in pocket)	
14.	Aeromagnetic Map of West Central Saskatchewan -----	124
15.	Histograms of Plagioclase Compositions and Specific Gravities of Basement Samples -----	134
16.	Flow Sheet Showing Methods of Separation -----	167
17.	Schematic Diagram of Extraction Train -----	173
18.	Typical Mass Spectrometer Strip Chart for Argon -----	177
19.	Facsimile of Calculation Sheet for K-Ar Age -----	178
20.	K-Ar and Rb-Sr Dates, Western Canada -----(in pocket)	
21.	Plot of Modal Quartz, K-Feldspar and Plagioclase for Silicic Plutonic Rocks -----	212
22.	Plot of Normative Q, Or, and Ab for some Average Sedimentary Rock Compositions -----	215

Tables

Table 1.	Data for Basement Wells from which Core Samples are Available -----	6
2.	Correlation Chart for Area I -----	37
3.	Regional Stratigraphy of Area II -----	49
4.	K-Ar Dates from Northern Manitoba -----	62
5.	Correlation Chart for Area III -----	67
6.	Stratigraphy of Area IV -----	71
7.	K-Ar Dates from Nelson River Gneissic Zone -----	74
8.	K-Ar Dates from Cross Lake-Knee Lake-Gods Lake-Island Lake Area -----	84
9.	Stratigraphy of Area V -----	86
10.	Stratigraphy of Area VI -----	90
11.	Modes of Igneous Rocks -----	138
12.	Modes of Metamorphic Rocks -----	145
13.	Descriptive Summary of Metamorphic Rocks -----	147

	Page
14. Map Areas Used for Comparative Purposes with Basement Samples -----	153
15. Percentage Distribution of Rock Types of the Shield and Basement -----	157
16. K-Ar Analytical Data and Dates for Basement Samples -----	193
17. K-Ar Analytical Data and Dates for Outcrop Samples -----	194
18. Comparison of K-Ar Dates on Co-existing Biotite and Hornblende -----	196
19. Data for Impure Hornblende and Pyroxene Separates -----	198
20. Summary of Pyroxene Dates -----	201
21. Rb-Sr Analytical Data, Dates, and Comparison with Co-existing Minerals Dated by the K-Ar Method -----	202

Plates

Plate 1. Basement Igneous Rocks, Southwestern Saskatchewan -----	235
2. Basement Igneous Rocks, West-central Saskatchewan and Other Areas -----	236
3. Basement Igneous and Metamorphic Rocks -----	237
4. Basement Metamorphic Rocks -----	238
5. Basement Metamorphic Rocks -----	239
6. Basement Metamorphic Rocks -----	240
7. Basement Metamorphic Rocks and Dated Rocks from Outcrop Areas -----	241
8. Dated Outcrop Rocks -----	242
9. Dated Outcrop Rocks -----	243

INTRODUCTION

General Statement

This thesis presents the results, interpretations, and conclusions from a primarily petrologic and geochronologic study of samples from the Precambrian basement of Saskatchewan, Manitoba, and adjacent shield and basement areas. The study forms a part of the continuing research project on the Precambrian of the western Canada sedimentary basin initiated by R. A. Burwash in 1950.

The investigation was undertaken with two main objectives in mind. The first was to describe the basement cores available from deep drilling in Saskatchewan and Manitoba, and to compare these and their regional distribution with the geology of the adjoining shield areas. The second purpose was to attempt to determine the position in the basement of the boundary between the Churchill and Superior geologic provinces mainly with the use of K-Ar age determinations.

The results of the investigation have been successful in determining the basement extent of the Churchill province in Saskatchewan and to a lesser degree of certainty in North Dakota and Montana. The boundary as suggested by geophysical data is tenable in the light of the age determinations presented in this study. The lithological composition of the basement of Saskatchewan appears to be no different than the Precambrian of the adjacent shield areas.

Location and Size of Area

The main area of study (fig. 1) forms the sedimentary region of Saskatchewan and Manitoba comprising a total of about 216,000 square miles.



INDEX MAP

////// Limit of main area of study



Figure 1.--Index map.

The remainder of Manitoba and Saskatchewan is made up of Precambrian shield and 22,000 square miles of Phanerozoic sediments adjacent to Hudson Bay.

The thesis area physiographically forms part of the Interior Plains which is further divided into the Central Lowland province to the east and the Great Plains province to the west (Lobeck, 1948).

Sample Availability and Distribution

Data for wells from which basement core samples are available are give in table 1. Cores from 43 wells were studied which included 32 from Saskatchewan, 5 from Manitoba, 5 from North Dakota, and 1 from Montana. Samples from the 37 wells in Saskatchewan and Manitoba have an areal density distribution of one sample per 5850 square miles, but the wells are not randomly spaced over the total areas as shown in figure 12. Sixteen of the wells are located along the southern part of the main area between 49 and 51 degrees latitude north, and 21 wells are located in a belt which approximately parallels the contact between the exposed shield and younger cover rocks. The central part of the sedimentary area of Saskatchewan has only one basement well from which a core is available.

In addition to the basement cores, outcrop samples from northern Saskatchewan, northern Manitoba, and Montana were obtained for dating purposes. Some of these samples were collected by the writer and the remainder were furnished by other workers.

Methods

The basement samples and dated outcrop samples were described using standard petrographic techniques and the specific gravity of the basement cores were determined. The basement rocks were classified on the basis of probable origin and grade of metamorphism, and the resulting compilation was compared with the composition of the adjacent shield. A total of 45 K-Ar dates were completed on biotite, hornblende, and pyroxene obtained from basement and outcrop samples. Potassium feldspars from two of the basement samples were dated by the Rb-Sr method. The geologic literature available on the shield areas adjacent to the main area of study was summarized and the outcrop dates were discussed and interpreted in light of this information. Available information on the structure of the basement both of the main area and adjacent areas was reviewed. Some geophysical data was qualitatively interpreted with regard to the regional fabric and possible structures in the basement rocks.

Previous Work

Publications concerned directly with the basement rocks of the main area of study are limited in number. Burwash (1957) described two cores from the area in conjunction with his study of the basement of Alberta. Meek (1958) on the basis of core and chip samples constructed a rather generalized basement geologic map of the area. Sawatzky, Agarwal, and

Wilson (1960) described some basement rocks from southwestern Saskatchewan in their report on helium occurrences of that area. Agarwal (1960) discussed a portion of the basement of west central Saskatchewan and interpreted the available aeromagnetic data.

Moss (1936) discussed the Precambrian surface of the United States mainly in terms of the various structural features which were known at that time. Tullis (1952) constructed a basement map of the Williston basin region of the Dakotas and Montana on which the rock types of 29 basement samples are plotted. A recent basement structure map of South Dakota is available and rock types are indicated (Steece, 1961). Kornfeld (1954) presented a basement geologic map of North Dakota based on gravity and seismic studies. Sloss (1950) mentions the basement of Montana in conjunction with his idea that the composition may have determined its positive or negative tendencies in later geologic time.

Numerous papers discuss the basement in terms of structures which may have influenced later developed features in overlying rocks. References will be made to many of these in later sections concerned with the structural features of the basement.

Table 1.--Data for basement wells from which core samples are available.

Index Sample No.	Well Name	Location	KB	TD	PC	SD	Rock Type
1	Imperial Goodsoil 8-11	8-11-62-22 W 3	1708	3461	3452	3460	Bio. qtz. monzonite
2	Seaboard Meadow Lake Crown 3	8-30-64-15 W 3	1564	2435	2399	2435	Bio. gneiss
3	Seaboard Meadow Lake Crown 1	13-21-61-15 W 3	1543	2773	2755	2767	Bio. granite
4	Canadian Seaboard Divide No. 2	7-14-56-17 W 3	2351	4333	4325	4332	Hyp. qtz. monzonite
5	Seaboard Meadow Lake Crown 2	9-21-63-8 W 3	1722	2061	2035	2061	Hbl.-bio. qtz. monzonite
6	Great Plains McDermott Smoothstone 1-36	1-36-63-5 W 3	1830	1923	1915	1921	Hbl.-bio. gneiss
7	Great Plains McDermott Home Musquash 8-8	8-8-64-2 W 3	2085	2028	2003	2006 2009 2017 2026	a. Bio. gneiss b. Amphibolite c. Bio. gneiss d. Bio. gneiss
8	Great Plains McDermott Home Hay 3-18	3-18-63-1 W 3	2127	2129	2107	2122	Garnet gneiss
9	Great Plains McDermott West Montreal Lake 5-22	5-22-62-26 W 2	1937	1858	1823	1851 1855	Altered bio. gneiss "
10	Great Plains Montreal Lake 2-5	2-5-61-24 W 2	1721	1825	1763	1820	Mica schist
11	Mobil Oil Von Mehren Lake X-8-15	8-15-52-2 W 3	1771	3297	3250	3290	Bio. gneiss
12	Imperial California Standard Ft. a la Corne 8-9	8-9-50-18 W 2	1433	2437	2393	2378	Metagreywacke and phyllite
13	Irex C-11-3	11-3-50-18 W 2	1370	3501		3056	Iron formation
"	Irex D-12-3	12-3-50-18 W 2	1423	3269		2170	Iron formation
14	California Standard Ratner 1-15	1-15-48-17 W 2	1425	2595	2543	2594	Mica schist
15	Triad Whitefox 12-15	12-15-52-14 W 2	1210	1790	1704	1785	Cordierite schist
16	Triad Whitefox 13-18	13-18-52-13 W 2	1215	1619	1586	1615	Bio. gneiss

Table 1.--Data for basement wells from which core samples are available (cont'd.).

Index Sample No.	Well Name	Location	KB	TD	PO	SD	Rock Type
17	California Standard	Bannock 15-5	15-5-46-9 W 2	2532	2529	2532	Altered granite
18	White Rose et al Bt. Denis	4-16-37-1 W 3	1833	5415	5383	5406-5410	Bto. gneiss
19	Geopos Annette	10-25-36-5 W 2	1844	3369	3360	3364-3369	Mica schist
20	Shell Swan River 1	9-1-37-28 W 1	1186	2047	2035	2044-2045	Microgranite
21	Tidewater Blawart Crown 1	14-10-27-25 W 2	1692	5955	5941	5955	Altered granodiorite
22	Mobil Oil North Richmond	31-1	2521	7440	7420	7422	a. sandstone (not p'd) b. Altered schist c. Propylite (?) d. Bto.-hbl. gneiss
23	Imperial et al Battle Creek	4-31	3072	7339	7240	7305	Metaquartzite
24	Mobil Oil Woodley Southern Dorrell	9-32-6-22 W 3	3458	8858	8808	8820	Granite
25	Delhi et al Rock Creek	2-4-10-19 W 3	3051	8777	8500	8768-8774	Chlorite granite
26	Mobil Woodley Southern Fonterton	15-3-17-18 W 3	2440	7256	7246	7255-7260	Porph. granite
27	Mobil Oil Woodley Sinclair Cantuar	2-21-16-17 W 3	2411	7312	7218	7285-7305	Porph. bto. granite
28	British American Wilhelm	1-9-17-14 W 3	2387	6755	6706	6735-6755	Rhyolite porphyry
29	Tidewater Johnstone Lake 1	9-20-12-2 W 3	2421	7790	7779	7785	Rhyolite porphyry
30	Geopos Baldwin	2-11-15-26 W 2	1937	7740	7682	7738	Bto. qtz. monzonite
31	Imperial Stoughton	3-27-18-11 W 2	2058	8834	8680	8830	Granodiorite gneiss
32	Bocony-Western Prairie Imperial	16-4-3-32 W 1	1617	8329	8315	8328	Bto. qtz. monzonite

Carlevale 1

Table 1.--Data for basement wells from which core samples are available (cont'd.).

Index Sample No.	Well Name	Location	KB	TD	PC	SD	Rock Type
33	4214 California Standard Daly 15-18	15-18-10-27 W 1	1614	5368	5359	5360	Altered bio. qtz. rock
34	4216 California Standard Wawanesa 3-1	3-1-8-18 W 1	1364	3826	3816	3825	Bio. gneiss
35	4233 Red River Hepner 2	3-1-5-2 W 1	797	1045	1042		Bio. gneiss
36	4235 Stony Mountain No.1	7-29-12-2 E 1	800	1009	708		Bio. gneiss
37	3798 Shell N. P. 32-33B	Sec. 33, T.22N., R.48 E.	2486	11,075	11,005	11,050	Pegmatite and amphibolite
38	4679 Amerada 1 Iverson-Nelson Unit	Sec. 2, T. 155 N. R.96 W.	2316	13,615	13,592	13,603	Altered syenite
39	4678 Amerada 1 Antelope Unit A	Sec. 1, T.159 N. R. 95 W.				15,128	Hyp. granulite
40	4682 Union Oil 1 Skjervheim	Sec. 28, T.159 N. R. 63 W.	1562	3408	3404	3408	Bio. gneiss
41	4680 Herman Hanson 1 Mueller	Sec. 20, T. 140N. R.65 W.	1567	3316	3305		Bio. qtz. monzonite
42	4681 Carter Northern Ordnance 1	Sec. 35, T.133 N. R. 75 W.	2026	5359	5353		Epidote-bio. gneiss

Explanation:

KB elevation of kelly bushing in feet above sea level.
TD total depth of well in feet below kelly bushing.
PC depth in feet to Precambrian surface.
SD depth in feet to core samples.

Note: See Appendix B for more complete rock names.

REGIONAL SETTING AND GENERAL GEOLOGY

The purpose of this section is to present the necessary background information for the regional basement study of Saskatchewan, Manitoba and adjacent parts of the United States. In order to suggest any petrologic and chronologic implications of the basement samples studied it is necessary to review the geology of the adjacent exposed shield areas. A brief discussion of the division of the shield into distinctive geologic provinces is presented and a résumé of adjacent shield geology is presented. The K-Ar dating work on outcrop samples completed during the present investigation and the results from other laboratories are incorporated into the various sections of the shield geology, because it is here that the dates are most readily interpreted. Where possible the geology of the areas is discussed in terms of regional stratigraphy. In some areas very little has been done with regard to the determination of Precambrian stratigraphy and it is necessary to describe these areas in terms of areal distribution of rock types and probable stratigraphic relations. In addition to the summary of outcrop geology a discussion of the Precambrian basement surface is presented. Of importance to this study are the structural features evident either in the buried Precambrian rocks or controlled by Precambrian features and recognized in the overlying sedimentary rocks.

Division of the Canadian Shield into Geologic Provinces

Apparently the first attempt to divide the Canadian shield into geologically similar areas or provinces was made by M.E. Wilson (1939, 1941). The main advantage of a division at that time was that it seemed safer and easier to correlate rock units within a geologic province than from one

province to another (M.E. Wilson, 1941, p. 274). Gill (1948) suggested a somewhat different division of the shield based to a large extent on dominant structural trends. Later Gill (1949) proposed names for the structural provinces and subprovinces. The subprovinces consisted of distinctive areas within the main provinces and these were classified as mountains, plains, or belted plains but not necessarily in a topographic sense. These were defined (Gill, 1949, p. 63) as follows: "Mountains are elongate belts of folded and faulted sediments and volcanics. Plains are areas of flat-lying sediments or volcanics, or both. Belted plains are areas of sediments or volcanics, or both, with a regional dip." This concept and division of the shield has not been drastically changed since it was first proposed.

J.T. Wilson (1949a, 1949b) arrived at a very similar division of the Canadian shield on the basis of trend lines and geophysical properties. He later (Wilson, et al. 1956) elaborated on the possible age relations of the provinces and the relation of ore deposits to structural boundaries. Wilson (1949a, p. 235) notes that . . . "the several provinces indicated . . . are believed to be primary orogenic belts, either single or multiple, distinguished by common rock types, uniformity of direction of foliation, and similarity of age determinations where these are available." The subprovinces are thought by J.T. Wilson (1949a, p. 235) to represent secondary units overlapping primary provinces. The overall distribution of the geologic provinces is explained by Wilson as the result of continental accretion.

Recent K-Ar dating on a shield-wide basis by the Geological Survey of Canada in addition to the great amount of reconnaissance mapping completed in the last decade, has added greatly to the knowledge of the division of the shield into provinces and subprovinces and their absolute and relative ages. Stockwell (1961, p. 108-119) discusses the division of the shield and describes the provinces and subprovinces briefly. The age of each main

province has been determined by the last major orogeny affecting that province and it is now thought that three such major orogenies have occurred in the Precambrian. These are (Stockwell, 1961, p. 114):

- (1) Kenoran at about 2500 m.y.
- (2) Hudsonian at about 1700 m.y.
- (3) Grenville at about 950 m.y.

Effects of all these orogenies have been recognized in the shield area of Minnesota, but the terminology used there is somewhat different (Goldich, et al., 1961):

- (1) Algoman at about 2500 m.y.
- (2) Penocean at about 1700 m.y.
- (3) Grenville at about 1100 m.y.

The subprovinces may or may not be the same age as the province in which they occur. This is especially true of the "belted plains" and "plains". For example the Athabasca and Thelon plains are subprovinces of the Churchill, but they are comprised of essentially flat-lying sandstones which lie unconformably upon the crystalline rocks.

A brief description of the dividing zones between the various provinces is given by Stockwell (1961). The provinces of most interest to the present investigation are the Churchill and Superior, occurring in Manitoba and Saskatchewan; and the dividing zone, the Nelson River valley. The general geology of the two provinces and the dividing zone is discussed in a later part of this chapter.

In figure 2 a sketch map shows the division of the Canadian shield as presently advocated by the Geological Survey of Canada. The major provinces and the time of the main orogeny affecting each are shown.

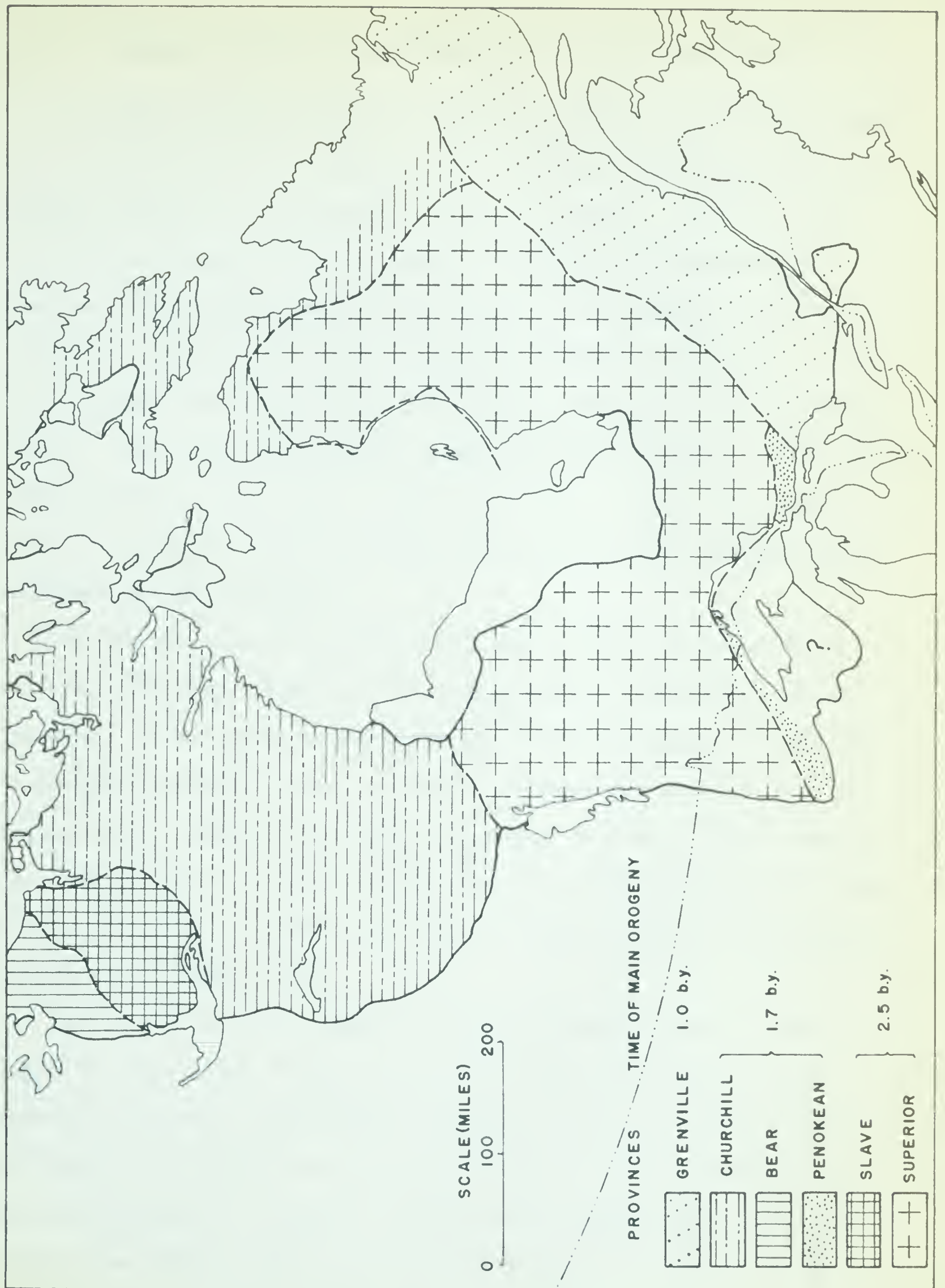


Figure 2.--Geologic provinces of the Canadian shield (modified after Lowdon, 1961).

Geology of Shield Areas Adjacent to the Main Area of Study

An attempt is made to discuss briefly the geology of the shield areas which are pertinent to the basement study of Manitoba and Saskatchewan and adjacent areas to the south because of their proximity. The main region discussed includes parts of the Northwest Territories, Saskatchewan, Manitoba, and Minnesota. In addition to areas of the Canadian shield described three areas of Precambrian outcrop in Montana are mentioned. These are the Little Rocky Mountains, The Little Belt Mountains and the Beartooth uplift. These areas are discussed because of their importance to the regional picture of the western Canada sedimentary basin. The Beartooth uplift is of additional interest because it is part of one of the three Archean nuclei recognized in North America.

The present discussion is not meant to be a complete review of all geologic literature referring to the region and many references are not included. In many parts of the region only reconnaissance-type information is available and most of this was used. Elsewhere many detailed reports are available, especially for areas of economic interest. Where feasible the detailed reports of limited areal coverage were incorporated, but some have been omitted because they add little to the knowledge of the regional geology of the various areas.

An attempt is made to compile a regional geologic picture of the region in terms of main rock types and their areal distribution, main structural features, stratigraphic relations of the various rock units, and correlations based both on geologic relations and available physical age determinations. A number of K-Ar age determinations were completed on samples from various parts of the exposed Precambrian during the course of

this investigation and these are included in the following discussion.

Where possible a sketch map of areas showing location and geologic relations of the samples dated are given. Age determinations of other laboratories are also presented.

The region is divided into areas for purposes of discussion and this division has been made both on a geologic and geographic basis. Lack of information has influenced the division in some parts of the region. The division into areas is shown on the sketch map (fig. 3) and the areas are listed below. Precambrian outcrop areas of Montana are also included in this section.

Area I includes northern Saskatchewan, northeastern Alberta, and adjacent parts of the Northwest Territories. The northern limit of this area is arbitrarily taken at 63 degrees north latitude and it has no geologic implication. The southern limit is marked by the Paleozoic rocks in Alberta, and the Athabasca series and latitude 59 degrees north in Saskatchewan. The area is not extended into Manitoba because of lack of information north of 59 degrees.

Area II is the main shield area of Saskatchewan. The southern limit is the Paleozoic-Precambrian contact. In the northern part of this area the eastern limit is arbitrarily taken as the Manitoba-Saskatchewan boundary and to the south the limit is the Tabbernor Lake fault.

Area III is northern Manitoba. The north limit of this area is 59 degrees north latitude. The southern boundary is the Paleozoic-Precambrian contact at the southwest and the Nelson River Valley on the southeast.

Area IV is the Nelson River Valley. This area is separated from areas to the north and south because of its geologically distinctive features,

and because it is thought to represent the boundary between the Churchill and Superior provinces.

Area V is central Manitoba. The northern limit is the Nelson River Valley and the southern termination is 53 degrees north latitude which more or less corresponds to a large terrane of dominantly granitic rocks.

Area VI is southern Manitoba. The southern boundary is arbitrarily taken at 49 degrees north latitude.

Area VII is Minnesota. The shield area of Minnesota is discussed for several reasons. It is the bordering shield to the basement of North Dakota. The geology and age relations are very well known and at least two age provinces are represented.

Area VIII includes the Little Rocky Mountains (fig. 10).

Area IX includes the Little Belt Mountains (fig. 11).

Area X is the Beartooth Uplift (fig. 13).

AREA I

The area described here is bounded on the east by Hudson Bay, on the west by Great Slave Lake, on the south by Lake Athabasca, and the Fond du Lac River, and arbitrarily to the north by latitude of 63 degrees. Recent reconnaissance mapping by helicopter has greatly added to the geologic knowledge of the northern part of the area (Lord, 1953, Wright, 1955, 1957).

The area is considered part of the Churchill Province and has been further divided into subprovinces as shown in figures 3 and 20 (Lang, 1961). Granite and gneissic rocks form the major part of the area. Lying within or upon this complex are metasedimentary rocks cropping out in a wide belt from just east of Great Slave Lake trending in a southerly direction into Alberta and Saskatchewan and then eastward in northern Saskatchewan and

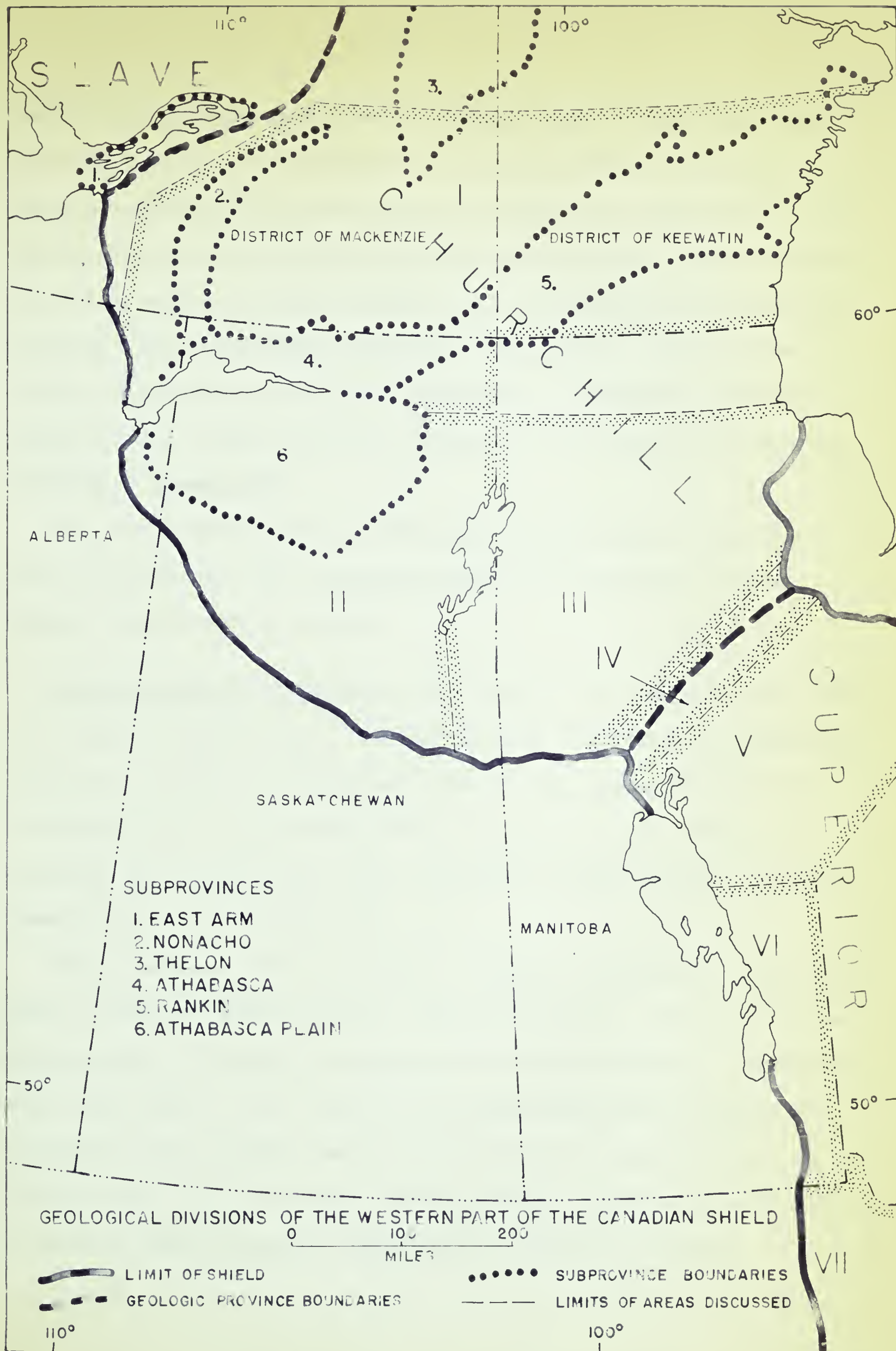


Figure 3.--Division of part of the western Canadian shield and areas discussed.
(division after Lang, 1961)

finally trending back northeastward to Rankin Inlet on Hudson Bay. Age relations among the metasedimentary rocks of the belt have not been completely resolved and the belt has been divided into subprovinces. The western part occurring mainly in the District of Mackenzie has been called the Nonacho subprovince, the southern part, the Athabasca subprovince and the eastern part, the Rankin subprovince (Lang, 1961). Another major division of the area is the Thelon subprovince, a large area covered by essentially flat lying Proterozoic sediments in the Districts of Mackenzie and Keewatin (Lang, 1961).

The area considered here is discussed as three units: (1) southern District of Keewatin, (2) southeastern District of Mackenzie, and (3) northern Saskatchewan and Alberta.

Southern District of Keewatin.--The area has been mapped by Lord (1953) and in part by Wright (1955). Much of the area is composed of Archean-type greenstones, granites, and gneisses. Some of the greenstones may be of Proterozoic age although evidence is not conclusive (Lord, 1953, p. 3). Generally, the volcanics and their derivatives are more abundant and widespread in the south (Wright, 1955, p. 5).

The greenstones have been invaded by granitic and gneissic rocks and in places altered to amphibolites near intrusive contacts. These granites and gneisses grade, in places, to gneisses derived from sedimentary and volcanic rocks (Lord, 1953, p. 6). Some of the Archean paragneisses composed of garnetiferous and pyroxene bearing gneisses may be pre-greenstone in age (Wright, 1955, p. 7). Both Lord (1953) and Wright (1955) have noted that at least two ages of granitic intrusions are present in the area.

The greenstone-granite-gneiss complex is overlain in places by Proterozoic sedimentary rocks (Lord, 1953) named the Hurwitz group by Wright (1955). These rocks are more or less localized in a belt extending from Nueltin Lake in the southern part of the area to Rankin Inlet on Hudson Bay, and form the Rankin subprovince (see fig. 3). The Hurwitz group is composed of quartzite, conglomerate, dolomite, and greywacke, and derived schists. These rocks have been moderately folded and in places intruded by granite (Lord, 1953, p. 6).

The relatively flat-lying Dubawnt group occurs in the northern part of the area. Wright (1955, p. 8) has divided this group into four units. The basal member is conglomerate containing boulders mainly of granite. A series of sandstones, arkoses, and siltstones overlie the conglomerate and are in turn overlain by porphyries. These igneous rocks are both intrusive and extrusive and have variable compositions (Wright, 1955, p. 10). The youngest member of the Dubawnt group is a conglomerate which in places contains pebbles of older Dubawnt sandstone and porphyry.

Late diabase and gabbro dikes strike predominately northwest and are post-Dubawnt in age (Wright, 1955, p. 15). Other basic and ultrabasic intrusive rocks occur in the area and although the relative ages are not known, many are probably "Archean" (Lord, 1953, p. 7).

Southeastern District of Mackenzie.--Wright (1957, p. 5) has noted several features of the area which are distinctive from the District of Keewatin. Conglomerate and porphyry are not as abundant in the Dubawnt group and the Hurwitz group is recognized only in a small area in the eastern part. Other differences are related mostly to the northern part of Wright's map area and are not considered here. The Nonacho metasedimentary rocks

occupy a stratigraphic position similar to the Hurwitz group to the east.

The pre-Nonacho rocks are dominated by granitic to granodioritic rocks of igneous and metamorphic origin. The oldest appear to be metasediments consisting of quartzite, greywacke, argillite, and associated volcanic rocks in places altered to greenstones and mafic gneisses. Terranes of high-grade paragneisses are common and these are typically associated with gneissic granitic rocks into which they grade imperceptibly. In the western part of the area the older metasedimentary rocks have been called the Tazin group (Wilson, 1941, Mulligan, 1956) and in other areas the similarity of the older metasedimentary rocks to those mapped as Tazin has been noted (Hoadley, 1955, Taylor, 1956). Regional introduction of potash feldspar has occurred in the southern part of the area. In the Snowbird Lake area the quartzites are feldspathized and porphyroblasts of K-feldspar are common in the paragneisses (Taylor, 1957). In the Hill Island Lake area, feldspathization is also a common feature (Taylor, 1956, Mulligan, 1956).

The granites and related intrusive rocks are commonly divided into two units. One unit is gneissic and typically associated with the paragneisses; the other is usually more massive, and in places appears to be intrusive into the gneissic granites and associated rocks. Porphyritic phases of the second type are not uncommon (Taylor, 1956, 1957). Taylor (1959b) reports garnetiferous hypersthene granulite which is locally intrusive into gneissic granite and older rocks in the Penylan Lake-Firedrake Lake area. The granulite forms a considerable portion of the map area.

The Nonacho group, comprised dominantly of conglomerate, slate, greywacke, arkose, and quartzite, commonly cross-bedded and ripple-marked; overlies the granitic and metasedimentary terrane described above, although

some of the granites are post-Nonacho in age. The post-Nonacho granites are differentiated only within the Nonacho belt, because elsewhere it has been impossible to determine the relative age. The main belt of Nonacho rocks occurs in the Nonacho Lake, Talston Lake and Fort Smith map-areas (Taylor, 1959c, Henderson, 1939a and b, Wilson, 1941). Minor Nonacho conglomerate and perhaps quartzite are present in the Hill Island Lake area (Mulligan, 1956) and the Penylan-Firedrake Lake area (Taylor, 1959b). In the Snowbird Lake area arkosic conglomerate, arkose, quartzite, and lenses of dolomite and limestone are present in small amounts. Taylor (1956) has not assigned these rocks to a specific group although they appear to occupy a stratigraphic position similar to either the Nonacho or Hurwitz groups. A possible northeasterly extension of the main Nonacho belt occurs in Wright's (1957) map-area where the sediments have been severely folded and appear to form a southerly plunging syncline. This possible Nonacho outlier is separated from the main belt by a few miles of granitic terrane (Wright, 1952).

The main Nonacho belt occurs on strike with an older belt of Tazin rocks. In the Fort Smith map area (Wilson, 1941) the Nonacho belt is abruptly terminated at Thekulthili Lake, and the continuing belt to the south is composed of more highly metamorphosed and intruded sediments of the Tazin group. If this apparent change from north to south is real, the Nonacho-Tazin unconformity occurs in the vicinity of the southern part of Thekulthili Lake.

The youngest group of sediments, the Dubawnt group continues into the northern part of the area (Wright, 1957) from the District of Keewatin.

Mafic intrusive rocks occur in minor amounts throughout the area and their ages relative to the other rock units are in places difficult to determine. However, the youngest rocks in all areas appear to be late basic

dikes of dioritic to gabbroic composition. Their general trend seems to be north and northeast. In the Penylan-Firedrake Lakes area, the late dikes are commonly garnetiferous (Taylor, 1959b).

Northeastern Alberta and Northern Saskatchewan.--This area has been mapped on a scale of four miles to the inch, and in places in much more detail. Alcock (1936) mapped the greater part, from 105 to 110 degrees west longitude and 59 to 60 degrees north latitude. Furnival (1941a and b) completed the Stony Rapids sheet and mapped the Porcupine River area to the east. The northeast corner of Saskatchewan, the Phelps Lake area, has recently been mapped on a four-mile scale by Tremblay (1960) and the northeast corner of Alberta is covered by the Fort Fitzgerald sheet (Riley, 1960).

Fairly detailed work has been completed in some areas. Godfrey has done considerable work in northeastern Alberta, and the Andrew Lake sheet has been published (1961). Koster has been engaged in one-mile mapping in the northwest corner of Saskatchewan and the Thainka Lake sheet is available (1961). Christie, (1953), Hale (1954a and b, 1955), Blake (1956a), and Fraser (1960) have mapped in the Goldfields and adjacent areas on a one-mile scale. Additional detailed work has been done in this area mainly as a result of interest in the uranium deposits. Colborne (1960, 1961), Johnston (1960, 1961), and Mawdsley (1957a) have mapped 15 minute quadrangles in the area covered by the Stony Rapids and Porcupine River four-mile sheets.

Regionally the bedrock of the area is dominated by granitic and gneissic crystalline rocks of both sedimentary and igneous origin. Lower grade metasedimentary and metavolcanic rocks are evident in places. Structurally the region is complex but there are certain general trends. In Alberta and northwestern Saskatchewan the dominant foliation and banding are essentially

in northerly directions. In the Goldfields area a well-developed northeast trend of foliation, banding, and faulting occurs. In the eastern part of the region similar northeasterly trends occur. Faults are main structural features in most parts of the area, and many seem to parallel the regional strikes of the rock units, although many are cross-cutting and it is difficult to generalize about any predominant direction.

The Tazin group of metasediments, metavolcanics, and derived gneisses is thought to be the oldest recognizable rock unit in most parts of the area. The rocks of this group in most places have been intensely folded, highly metamorphosed, and extensively intruded by granitic and to a lesser extent basic rocks. Overlying the Tazin group and associated granitic rocks are two younger sedimentary units. The Martin formation, of limited occurrence in the Goldfields area, was thought to correlate with the Athabasca sandstones which cover a large area south of Lake Athabasca, but recent information has indicated that correlation is unlikely and the Athabasca sandstone probably overlies the Martin formation unconformably. Both of these units are intruded by basic rocks.

Thus, the rocks of the area have been divided into the following five more or less distinctive groups: (1) Tazin group, comprised mainly of high-grade gneisses, (2) post-Tazin--pre-Martin formation intrusions, mainly granitic, (3) Martin formation conglomerates, sandstones, and associated basic extrusive rocks, (4) Athabasca sandstones, (5) post-Athabasca basic intrusions. These units are discussed in more detail in the following paragraphs with special references to areal distribution and regional variations.

TAZIN GROUP: In this area ancient metasedimentary and metavolcanic rocks belonging to the Tazin group as first named by Camsell (1916) have been mapped and described in areas from the Alberta-Saskatchewan border as far east as the Porcupine River area (Alcock, 1936, and Furnival, 1941b). In northeastern Alberta, Riley (1960) recognized metasedimentary rocks lithologically similar to Tazin rocks cropping out to the north. In the northeast corner of Saskatchewan, in the Phelps Lake area, Tremblay (1960) has not mapped Tazin rocks as such but notes that quartzitic sediments in part are probably the oldest rocks of the area.

Rock types within the Tazin group vary both as a result of original composition and degree of metamorphism. Alcock (1936) lists the following rock types in the legend of his map sheets: limestone, dolomite, secondary silicate rock, quartzite, argillite, conglomerate mica schist, mica gneiss, lavas, and volcanic fragmental rocks. In the Goldfields area Christie (1953, p. 8-19) described the Tazin rocks in some detail. Here quartzite, dolomite and dolomitic quartzite, ferruginous quartzite, conglomerate, and associated volcanic and indeterminate mafic rocks are included in the Tazin. In places moderate to high grade metamorphism has produced rocks containing diopside, tremolite, cordierite, garnet, andalusite, and sillimanite, in addition to the more common metamorphic minerals. To the east, in the Oldman River area, Blake (1956a) describes similar rock types in the Tazin group and there appears to be a more or less continuous belt of Tazin rocks from this area across the Fond du Lac area (Alcock, 1936). In the Stony Rapids (Alcock, 1936, Furnival, 1941a) and western part of the Porcupine River (Furnival, 1941b) areas, Tazin rocks composed of metamorphosed sedimentary and volcanic rocks are similar to those described in areas to

the west. Colborne (1960, 1961) and Johnston (1960, 1961) have described some of these in detail. Recognizable Tazin rocks appear to decrease in abundance to the east in the Porcupine River area (Furnival, 1941b) and are replaced by undifferentiated biotite and biotite-hornblende gneisses. The grade of metamorphism in most areas has been high but local variations have been noted. Christie (1953, p. 65) describes a general decrease in grade of metamorphism from the Oldman River area where pyroxene amphibolites occur (Blake, 1956a) to the west around Camsell Portage where rocks of the greenschist facies are dominant. In areas to the east metamorphism has been intense and perhaps in the granulite facies (Colborne, 1960, p. 18).

From time to time attempts have been made to subdivide the Tazin group. Alcock (1936, p. 10) suggested that more than one series of rocks were represented in the Tazin group. In the Goldfields area Alcock (1936) recognized a younger series of quartzite, conglomerate, and iron formation which he named the Beaverlodge series. More recently Christie (1953) remapped the area in detail and finding no unconformity between the supposed Beaverlodge and Tazin included the former in the Tazin group. Hale (1954a and b, 1955) classified much of the Tazin group west of Goldfields as Athabasca series. He divided the Athabasca series of this area into an "Upper Part" and a "Lower Part" separated by an unconformity. He noted that the "Lower Part" was highly folded but not considerably metamorphosed. More recently Fahrig (1961) in conjunction with his detailed study of the Athabasca

series re-examined areas underlain by Hale's "Lower Part" and concluded that these rocks are, as Alcock (1936) had originally mapped, just low-grade remnants of the Tazin and shouldn't be treated as a distinct unit.

In the northwest corner of Saskatchewan Alcock (1936) mapped a considerable area around Thainka Lake as being underlain by Tazin rocks. Koster (1961), in the same area, has recently found good evidence to indicate more than one age of metasedimentary rocks. A major lineament in the area is the Tazin fault, which is curved but trends mainly north-south. East of the Tazin fault Koster has mapped an "older basement complex" composed of poorly foliated granitic rocks, well to moderately foliated quartz dioritic rocks, and minor amphibolite (1961, p. 9-10). Overlying this older basement with apparent unconformity are a group of red gneisses. Where the grade of metamorphism is locally reduced Koster has recognized impure arkoses, conglomeratic arkoses, and conglomerates which are localized near the apparent base of the red gneiss section. In the western part of the red gneiss belt and intimately associated with it in places, Koster (1961, p. 55) has mapped a pegmatitic migmatite complex composed of impure quartzites, biotite and chlorite schists, biotite-sericite-quartz-feldspar schists, and meta-arkoses. Gneisses and rocks with porphyroblastic feldspar are locally important. This pegmatitic migmatite complex appears to be the southern extension of the Tazin group as mapped in the Hill Island Lake area to the north. Further west a complex of metasedimentary and metavolcanic rocks crop out. This band passes through Waugh Lake where Watanabe (1961) has identified the major units as feldspathic wacke, impure arenite, siltstone, siliceous conglomerate, tuffaceous rocks, schist, phyllonite, and conglomerate of debatable origin.

Relations between the metasediments and adjacent units are largely obscured by faulting. In places the metasediments appear to grade into the pegmatitic migmatite (Koster, 1961, p. 17) but the evidence is not conclusive.

The mapping of Tazin rocks nearly all the way across northern Saskatchewan by Alcock (1936) and later workers without the benefit of outcrop continuity raises some doubt as to the validity of such a regional correlation especially when the structural relations are in places so complex. The reasoning behind this correlation is apparently based on lithologic similarities and relations to intrusive rocks.

POST-TAZIN--PRE-MARTIN INTRUSIONS: At least one post-Tazin period of granitic intrusion, metamorphism and granitization is recognized in most parts of the region. Alcock (1936) mapped large areas of hybrid gneiss, part of which he thought was Tazin which had been injected and altered by granitic material. Christie (1953, p. 69-72) discusses the granitization in the Goldfields-Martin Lake area and concludes that most of the granites are of metasomatic origin. Igneous granites occur but they are difficult to distinguish from those of metasomatic origin (Christie, 1953; Blake, 1956a).

Basic intrusions belonging to this group are varied in composition. In the Goldfields-Martin Lake and adjacent areas lamprophyre dikes occur (Christie, 1953; Blake, 1956a). Noritic rocks have been mapped in the Fond du Lac and Stony Rapids areas (Alcock, 1936; Blake, 1956a; Furnival, 1941a; Colborne, 1960, 1961), but the origin of these may be metamorphic rather than igneous. Some of the mafic gneisses occurring within the Tazin group may be of igneous origin but if so they pre-date the main

period of metamorphism as evidenced by their altered condition.

MARTIN FORMATION: This unit includes the conglomerates, arkoses, and associated basic volcanic rocks occurring mainly around Martin Lake. (See Alcock, 1936; Christie, 1953 for detailed descriptions). Until recently the rocks of this formation exposed north of Lake Athabasca have been correlated with the more flat-lying sandstones south of the Lake. A recent study of the Athabasca series indicates that it is doubtful whether the two units are correlative and an unconformity representing a period of erosion possibly separates the two units (Fahrig, 1961, p. 31-32). Lithologically the two sequences are dissimilar, suggesting different sedimentary environments.

ATHABASCA SERIES: Fahrig's recent study (1961) has added greatly to the geologic knowledge of a group of rocks which though long known have been neglected in terms of detailed work. The Athabasca rocks consist of interbedded shale, sandstone, and conglomerate (Fahrig, 1961, p. 7), but sandstone is by far the predominant rock type. From the study of many current structures Fahrig (1961) has concluded that the Athabasca sandstones were derived from a previously existing sedimentary terrane to the east and southeast. Within the main area of Athabasca sandstones Blake (1956b) discovered some highly folded calcareous rocks which he named the Trout Lake limestone, since renamed the Carswell formation (Fahrig, 1961). The dolomitic beds are folded and associated with an interesting crypto-volcanic structure some 18 miles in diameter (Fahrig, 1961, p. 20).

POST-ATHABASCA INTRUSIONS: Basic dikes are known to intrude the Athabasca formation in several places (Fahrig, 1961, p. 15-16). In the Goldfields area late diabase dikes intrude the Martin formation but since they are thought to be related to the volcanic rocks within the Martin formation (Alcock, 1936 and Christie, 1953), they may be older than the post-Athabasca dikes.

Regional Correlations and Dates.--The Geological Survey of Canada has completed many K-Ar age determinations from this area (Lowdon, 1960, 1961). A considerable number of K-Ar dates on mica and hornblende have also been completed at the University of Alberta (Burwash and Baadsgaard, 1962, Godfrey and Baadsgaard, 1962, and the present investigation, of which some are reported by Burwash, et al, 1962). Prior to the K-Ar dating much work had been done on uranium minerals, mainly from the Goldfields area, and the results are summarized by Eckelmann and Kulp (1956, 1957). The data for the dates determined during the present investigation are given in table 17.

A plot of the K-Ar dates available (fig. 20) reveals that the part of the area in the Northwest Territories seems to be characterized by a wide range of dates. Many are around 1.7 b.y., but some though older are generally less than the 2.5 b.y. dates which characterize the Kenoran orogeny. The dates about 1.7 b.y. represent the effects of the Hudsonian orogeny. The older dates can be interpreted reasonably in two ways: (1) the dates are real and represent actual events, (2) the dates are survival values from Archean rocks and represent the degree of outgassing caused by the later Hudsonian orogeny. Burwash and Baadsgaard (1962) have resolved the problem and suggest the latter alternative to be most likely. In the

vicinity of Thekulthili Lake they have dated muscovite from boulders in the Nonacho conglomerate at 2.4 b.y. whereas biotite from the underlying basement complex yielded dates of 1.8 b.y. Hornblende from the older complex dated at 2.24 b.y. also suggests an Archean age (Burwash and Baadsgaard, 1962). In Saskatchewan a similar date of 2.44 b.y. was obtained on hornblende from the older basement complex mapped by Koster (1961). (See AK 277, table 17). The implications are that at least part of this area is geologically related to the Slave province of Archean age. During Lower Proterozoic time sediments were deposited on an older continental basement shelf of the Slave province and at the close of this period the older basement was partially remobilized (Burwash and Baadsgaard, 1962).

The possible extent of the older shelf region is not known. The 2.44 b.y. old hornblende from northwestern Saskatchewan suggests that it extended at least that far south, and the 2.35 b.y. date on hornblende from a cobble in the Tazin conglomerate cropping out in the Stony Rapids area may also indicate its extent. If this idea proposed by Burwash and Baadsgaard (1962) can be reasonably applied to the area as a whole then any regional correlation based solely on K-Ar dates becomes hazardous. The two orogenies can in places be resolved at 1.7 and 2.5 b.y., but if, for example, biotite yields a date of 1.7 b.y. it is not known whether the absolute age of the rock is Lower Proterozoic or Archean. This situation is generally true in dating minerals from any metamorphic rock but in a region of such complex and lengthy history the problem is that much greater. Eventually by dating additional minerals by the K-Ar method, and using different methods the problem will be solved. In the following sections the ages of the various geologic units are discussed in light of the available radioactive dates.

AGE OF THE TAZIN GROUP: If the Nonacho group lies on an Archean basement approximately 2.5 b.y. old and the Tazin is actually part of this basement as implied by Wilson (1941) then an Archean age for the Tazin is indicated. The dates obtained by the Geological Survey of Canada (Lowdon, 1960, 1961) on Tazin metamorphic rocks and post-Tazin intrusions are mostly in the range of 1.7 to 1.8 b.y. although a pegmatite from Viking Lake gives a biotite date of 2.02 b.y. (See fig. 17). The validity of this 2.02 b.y. date reported by Lowdon (1960, p. 19) is questionable even though concordant U-Pb dates from the same pegmatite are in approximate agreement (Lowdon, 1961, p. 120). Four laboratories have dated minerals from the Viking Lake pegmatite and the dates in b.y. are listed below:

	(1)	(2)	(3)	(4)
K-Ar (biotite)	2.02	1.78		
Rb-Sr (biotite)		1.84 (recalculated)		
206/238	2.00	1.79	1.85	1.53
207/235	1.95	1.83	1.88	1.72
207/206	1.92	1.85	1.92	1.87
(1) Lowdon, (1961, p. 120)				
(2) Aldrich, et al (1958, p. 1128)				
(3) Wasserburg and Hayden (1955). (See Eckelmann and Kulp, 1957, p. 1137)				
(4) Eckelmann and Kulp (1957, p. 1137)				

The U-Pb dates of (1), (2), and (3) are on uraninite and (4) is on uranothorite. Individually the U-Pb dates of laboratories (1), (2), and (3) are concordant and the results of (2) and (3) are essentially in agreement. The agreement between the K-Ar date on biotite and the U-Pb dates in (1) are good. The agreement is equally good in (2) but the dates are considerably less in magnitude than those of (1). With regard to the biotite

date in column (1) Traill (see Lowdon, 1960, p. 19) says that the biotite . . . "was undoubtedly formed at the time of original crystallization of the pegmatite and there is no evidence of subsequent recrystallization." However, some alteration is indicated by the low K value of 3.07 per cent reported for this biotite (ibid, p. 19). Aldrich et al (1958, p. 1132) note that the biotite which they dated has been partly chloritized as evidenced by a poor X-ray pattern and the K_2O content of 4.93 per cent. Another factor adding to the uncertainty of the K-Ar date reported by Lowdon (1960) is the amount of radiogenic argon present in the determination. Lowdon reports 75 per cent radiogenic argon whereas Aldrich et al (1958) report 96 per cent in their determination.

All in all the concordant U-Pb ages reported by Aldrich et al (1958) and the agreement with K-Ar and Rb-Sr dates on biotite are more convincing than the dates reported by Lowdon (1960) on the same minerals species. The reason for the discrepancy between the results of the two laboratories is not known, but may be in part analytical.

Other post-Tazin intrusions have been dated at the University of Alberta. (See table 17; fig. 20). One is a pegmatite from which muscovite gave an age of 1.74 b.y. (KA 120) and the other is a porphyritic biotite granite (fig. 4) dated at 1.72 b.y. (AK 174). Both are from the Stony Rapids area. All of the dates mentioned so far in regard to the age of the Tazin are minimum ages because they are either from post-Tazin intrusions or metamorphosed phases of the Tazin group. On the basis of U-Pb dates Eckelmann and Kulp (1956) concluded that the Tazin group must be older than 2.2 b.y. This suggested minimum age is based on highly discordant U-Pb dates and must be considered at best tentative. Some recent K-Ar dates may indicate a maximum age for the Tazin group. The writer collected a cobble from a

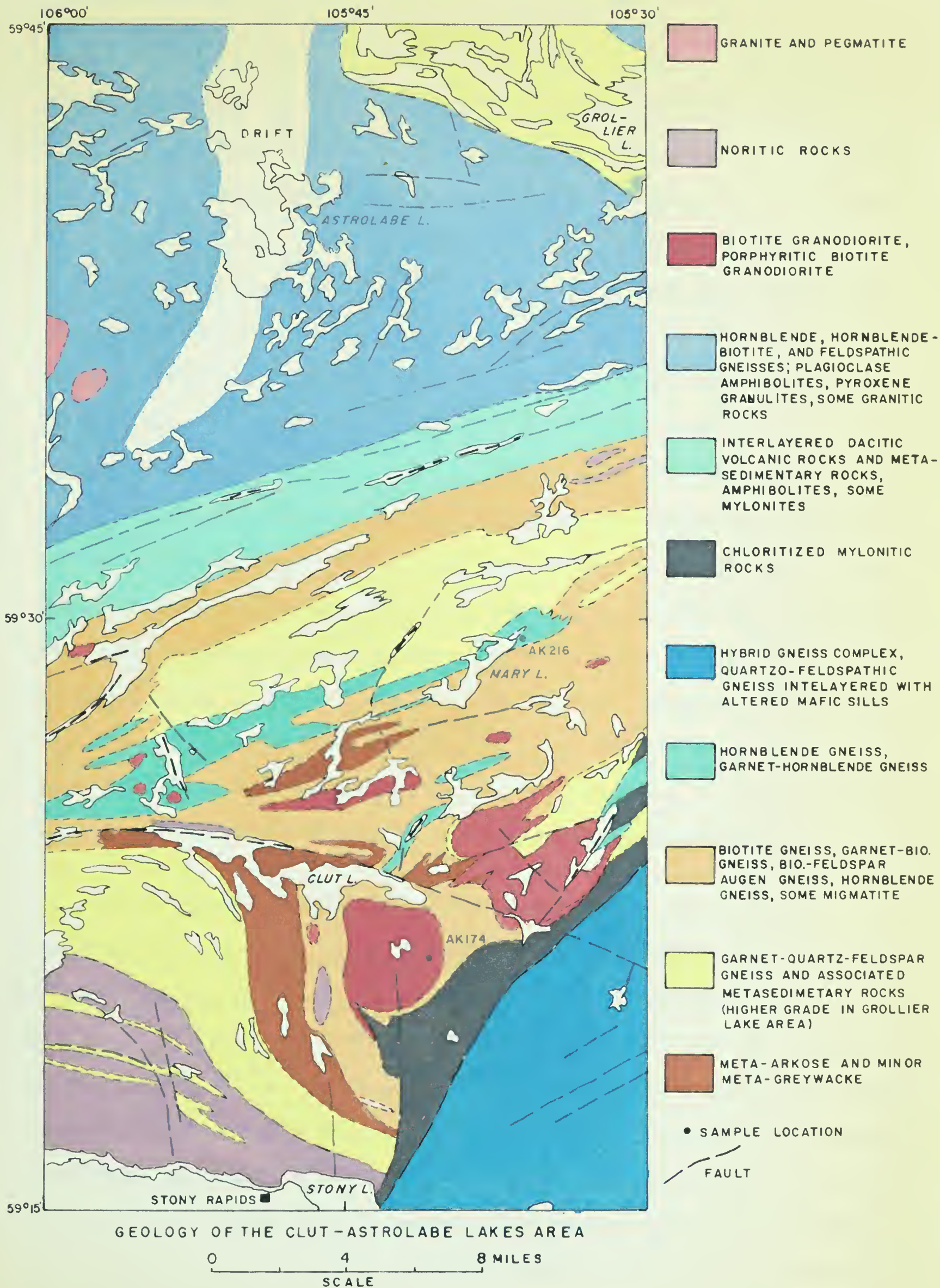


Figure 4.--Geology of the Clut-Astrolabe Lakes area (generalized after Colborne, 1960, 1961; Johnston, 1960, 1961).

Tazin conglomerate cropping out in the Stony Rapids area (fig. 4) and hornblende (AK 216) from the cobble is dated at 2.35 b.y. Koster submitted a hornblende-bearing Sample of his "older basement" and, as mentioned before, it is dated at 2.44 b.y. (AK 277). If this older basement is considered pre-Tazin in age then a maximum age of the Tazin group may be indicated by this number. These maximum dates for the Tazin do not agree with the geologic evidence in the Fort Smith area (Wilson, 1941) which combined with the K-Ar dates from the area indicate a pre-Nonacho or Archean age.

An alternative explanation for the 2.4 dates on hornblende (AK 216 and AK 277) is that the hornblende either formed or was completely outgassed at the time of metamorphism of the Tazin group which occurred at about 2.4 b.y. ago. According to this interpretation the Tazin group would be Archean in age. This possibility is difficult to evaluate at the present time. The situation is complicated by the fact that the rocks mapped as Tazin in one area may not be correlative with those mapped as Tazin in other areas. The solution has not been attained by the age determinations nor by the geologic mapping and to say that further work is needed is an understatement.

AGE OF THE MARTIN FORMATION: There are few dates yet to indicate precisely the age of the Martin formation. Eckelmann and Kulp (1956) concluded that the age of the Martin formation was greater than 1.9 b.y. on the basis of many discordant U-Pb dates from the epigenetic deposits of the area. Robinson (1955, p. 92, 93) however, in his comprehensive report on the uranium deposits of the Goldfields area presents a number of U-Pb dates and concludes from these that the syngenetic deposits (pegmatites) were formed about 1.7-1.8 b.y. ago. The earliest epigenetic vein deposits formed later at about 1.5 to 1.6 b.y. ago and were subsequently reworked and redeposited at various

times. This interpretation is more consistent with the other radioactive dates from the area.

Geologically it is known that the Martin formation overlies unconformably Tazin and associated granitic rocks from which biotite gives dates of 1.7 to 1.8 b.y. As mentioned before the Martin formation is folded, faulted and associated with mafic igneous rocks. However, it does not appear to have undergone a regional metamorphism similar to that which affected the Tazin rocks. Assuming the mica K-Ar dates represent a regional metamorphism and a time at which the rocks containing the micas were uplifted beyond a certain zone above which mica ceased to lose radiogenic argon, the maximum age of the Martin formation would be 1.7 to 1.8 b.y. less the time required for removal by uplift and erosion of the crustal block above the mica bearing rocks which now are exposed at the sub-Martin formation unconformity. This probable maximum age for the Martin formation is consistent with Robinson's (1955) age of early epigenetic uranium deposits, some of which occur in the Martin formation.

AGE OF THE NONACHO GROUP: As mentioned before recent findings of Burwash and Baadsgaard (1962) indicate that the Nonacho rocks lie, at least in part, on an Archean basement. Thus, a maximum age of about 2.5 b.y. is implied. A minimum age for the Nonacho series has not been satisfactorily established although Lowdon (1961, p. 33) reports a date of 2.00 b.y. for a paragneiss which may be Nonacho but unfortunately the outcrop area is separated from the main belt by a few miles of granitic terrain and correlation is impossible to prove. A probable minimum age for the Nonacho is 1.7 to 1.8 b.y. but as yet no definite post-Nonacho granites have been dated.

AGE OF THE HURWITZ GROUP: The Hurwitz group has not been satisfactorily dated. Lowdon (1961, p. 37) reports a date of 1.59 b.y. on pre-Hurwitz gneiss but mentions the possibility that the date represents a later metamorphism.

AGE OF THE DUBAWNT GROUP: One K-Ar date has been obtained from the Dubawnt igneous rocks (Lowdon, 1960, p. 17) which is 1.52 b.y. Matters are complicated by a more recent date of 1.72 b.y. on a lamprophyre correlated with the Dubawnt igneous rocks on geological evidence (Lowdon, 1961, p. 36). A maximum age for the unaltered Dubawnt rocks is given by a biotite date of 1.80 b.y. from a pre-Dubawnt quartz monzonite (Lowdon, 1961, p. 38).

AGE OF THE ATHABASCA SANDSTONES: In the vicinity of Cree Lake, Saskatchewan diabase dikes intrude the Athabasca series. Hornblende from one of these diabases was dated at 1.23 b.y. (AK 263) and this gives a minimum age for the Athabasca rocks. A maximum age is given by the dates discussed previously from the Tazin terrane north of Lake Athabasca. Biotite from a paragneiss cropping out east of the main exposures of Athabasca rocks yielded a date of 1.67 b.y. (Lowdon, 1961, p. 40) and this confirms the maximum age suggested above.

Attempts at regional correlation based mainly on geologic evidence and reasoning have been made. Blackadar and Fraser (1960) summarized the Precambrian geology of the Canadian Arctic and presented a speculative correlation chart. Brown and Wright (1957) have reviewed the Proterozoic rocks of the Northwest Territories and Saskatchewan and discussed possible correlations. The recent radioactive age determinations have solved some correlation problems but introduced many more. The following speculation on regional correlation is based mainly on the previous attempts, the K-Ar dating, and

the present review of general geology taken from some of the maps and reports covering the area.

The regional geology may be generalized as follows. The oldest rocks of the area consist of metamorphic equivalents of sedimentary and volcanic rocks which have been folded and invaded by intrusions of varying but dominantly granitic compositions. In the District of Mackenzie and perhaps in Saskatchewan parts of this older complex are represented by the Tazin group and associated intrusions. In the District of Keewatin and elsewhere in the District of Mackenzie greenstones and metasedimentary rocks occur but they have not been specifically correlated with the Tazin group or the Yellowknife group occurring in the vicinity of Great Slave Lake. In Saskatchewan the Tazin group as it is presently recognized may consist of units considerably different in age.

Lying on the older complex of moderate to high grade metamorphic rocks of Archean age are younger sedimentary rocks. These have been named the Nonacho and Hurwitz groups in the Northwest Territories. Part of the Tazin group of Saskatchewan may be equivalent in time to the Nonacho group. All three of these groups were intruded by granitic rocks, probably during the Hudsonian orogeny.

The youngest sedimentary rocks of the area are the Athabasca series and the Dubawnt group, both of which are intruded by late diabase dikes. The Martin formation of the Goldfields area may underlie the Athabasca series unconformably.

A very generalized correlation chart is shown in table 2. Undoubtedly as more geologic work and radioactive age determinations are completed the regional picture of the area will be greatly clarified. Until that time, lack of evidence for many of the relations necessitates broad speculations.

Table 2. Correlation chart for Area I

Age	Northern Saskatchewan	District of Mackenzie	District of Keewatin
Middle	Diabase	Diabase	Diabase
Proterozoic	- - - - -	- - - - - Intrusive Contact - - - - -	- - - - -
	Athabasca series	Dubawnt group	Dubawnt group
	- - Unconformity? - -		
	Martin formation		
	- - - - -	- - - - - Unconformity - - - - -	- - - - -
-----	Granite and related rocks	Granite and related rocks	Granite and related rocks
Lower	- - - - -	Intrusive and gradational contact - - - - -	- - - - -
Proterozoic		Nonacho group	Hurwitz group
		- - - - -	- - - - - Unconformity - - - - -
	Granite and related rocks	Granite and related rocks	Granite and related rocks
-----		- - - - -	- - - - - Intrusive Contact - - - - -
Archean	"Older complex"	Tazin group and	Greenstone and
		other metamorphic	paragneisses
		rocks	("older paragneisses"?)

AREA II

Much of the area has been mapped on a scale of one inch to four miles by the Geological Survey of Canada. Two sheets on a scale of one inch to eight miles are useful in obtaining a regional picture of the area (Rice, 1951, 1953). Some areas have been mapped in more detail and the reports and maps of the Saskatchewan Department of Mineral Resources are excellent references.

The most characteristic feature of the area is the remarkably uniform regional northeast orientation of banding, foliation, gneissic belts, and other structural features. These major regional structures extend from Lac la Ronge and areas to the west, northeast as far as Wollaston Lake and perhaps beyond. In the Lac la Ronge and Ile 'a la Crosse areas the dominant trend varies from north-northeast to east-northeast (Frarey, 1950a; McLarty, 1936a and b), whereas at the northerly end of the belt the trend is remarkably consistent at N. 45° E. (Fahrig, 1958).

Faulting occurs throughout the area, but perhaps the most significant feature is the Tabbernor Lake fault which appears to separate the Kiseynew gneisses on the east from the somewhat lower grade metamorphic rocks on the west. The fault strikes north from the southern extremity of the shield, perhaps as far north as Numabin Bay on Reindeer Lake (Kirkland, 1958). The displacement along the fault is not absolutely known but it is thought that the eastern block moved up and northward relative to the western block (Kirkland, 1958). Other faults occur in the area with varying attitudes but the main directions of strike seem to be north, west, northwest, and northeast. The Tectonic Map of Canada (Derry, 1950) shows several major faults trending northeast parallel to the regional structural pattern.

Throughout the area there seems to be certain similarities in rock types, metamorphism, and intrusive relationships. Almost everywhere metamorphism has reached a fairly high grade and widespread granitization has accompanied the injection of granitic material. A variety of metasedimentary rocks have been described from different parts of the area but certain types such as derivatives of impure sandstones, pelitic rocks, and limey rocks are regionally important. Granitization has complicated mapping in many parts of the area because all gradations appear to exist between recognizable metasedimentary rocks and massive granites.

For the sake of convenience, the rock types and general geology are described beginning in the northeast and progressing towards the southwest and west. The sub-areas discussed are based on the four mile map sheets of the Geological Survey of Canada. Where more detailed reports are available, these are discussed under the sub-area in which they occur.

Wollaston Lake.--Fahrig (1958) mapped the Wollaston Lake area and described the rocks in more detail than is usually found in the marginal notes of four-mile map sheets. The least altered metasediments have been derived from greywacke, argillite, quartzite, arkose, conglomerates, and calcareous rocks. Bedding is about the only primary structure that has survived metamorphism. The arenaceous sediments now contain biotite and garnet with the usual quartz and feldspar. An intensely deformed conglomerate contains granitic and dark cobbles. Hornblende gneisses and schists are thought to have been derived from basic igneous and calcareous sedimentary rocks. A transitional series of metamorphic rocks forms more than one-half of the area and grades into homogeneous, locally porphyritic, pink biotite granite.

Reindeer Lake-Spalding Lake.--Weeks (1941a and b) has described similar rocks south of Wollaston Lake. He considers the oldest rocks to have been of sedimentary and volcanic origin which were first intruded by basic rocks in the form of sills, dikes, and stocks and then metamorphosed, granitized, and intruded by granitic rocks. The units of mainly sedimentary origin consist of banded quartzo-feldspathic gneisses associated with pegmatitic stringers. Approximately 70 per cent of the area is underlain by varieties of granitic rocks ranging in composition from quartz diorite to granite, the latter predominating. One small body of massive, pink, aplitic granite may be younger than most of the other granitic bodies.

Foster Lake--Oliver Lake.--Alcock (1939) and McMurchy (1938a and b) have done reconnaissance mapping in these areas. In addition to the garnetiferous paragneisses, biotite schists, quartzites, argillites, and transitional gneisses, a belt of volcanic and sedimentary rocks occurs near Windrum and Waddy Lakes and continues some distance to the southwest. Byers (1949) and Miller (1949) have described this assemblage in detail. In the sedimentary unit greywacke, argillite, quartzite, and derived schists are the main rock types. The greywackes locally exhibit well-developed graded bedding. The volcanic units consist of acidic to basic flows with some felsitic intrusions and pyroclastic rocks. In places the volcanic and sedimentary rocks are conformable and the sediments are definitely older (Byers, 1949), but in others there is evidence for a younger series of sedimentary rocks (Miller, 1949). A conglomerate in this younger series contains cobbles of felsite, granite, and basic volcanic rocks (Miller, 1949; McMurchy, 1938a). These units have been folded, metamorphosed, and intruded by granitic rocks. Metamorphism has not been as intense as in the surrounding areas. Miller (1949) notes that metamorphism has been in the albite-epidote-amphibolite (upper greenschist) facies, and locally, a lower grade.

The granitic cobbles in the younger conglomerate are suggestive of two periods of granitic invasion. It is interesting to note that McMurchy (1938a) in the eastern part of the Foster Lake map area mapped an "older" quartz diorite body. It is not in contact with the larger bodies of granite but granite dikes cut the quartz diorite. Possibly this intrusion represents the older pre-conglomerate--post-greenstone intrusive activity; unfortunately, it is not in direct contact with the conglomerate so it cannot be proven that an unconformable contact exists.

Other parts of this area have been mapped in detail. In the Middle Foster Lake area (Mawdsley, 1957b) the northeast trending structures are especially evident because of the detailed scale of mapping. The major units are fine-grained biotite granulites, garnetiferous-cordierite-sillimanite-gneisses, minor impure marbles and derived calc-silicate rocks, augen gneisses, and banded granitic gneisses in places containing amphibole and pyroxene. These are intruded by granitic rocks of various compositions. An anticline is indicated in the central part of the area and overturning to the southeast is suggested by the predominant northwest dips of the beds and foliation.

South of Middle Foster Lake, Money (1961) has mapped the Barnett Lake area. Here the dominant strike of banding and foliation is approximately N. 30° E. A band of paragneisses and associated rocks about five miles in width crops out diagonally across the map-area and is bordered on either side by granitic intrusive rocks. The metasedimentary belt is composed of meta-arkose; quartzite; meta-conglomerate; biotite-hornblende gneiss, granulite, and associated migmatitic rocks; and biotite schist and granulite. Cordierite and sillimanite bearing rocks form a mappable unit. Augen gneisses and migmatites also occur. Money (1961) suggests that the original sedimentary sequence consisted of arkoses, pelitic sediments, and interlayered volcanics

or impure calcareous or dolomitic sediments. Metamorphism in the almandine-amphibolite facies has converted these into a variety of schists and gneisses. The main belt is thought to form an anticlinal structure with a horizontal axis and locally overturned (Money, 1961, p. 26). Two major sets of faults strike northeast and northwest.

Similar high grade metamorphic rocks have been recognized in the Brabant Lake area just south of the Waddy Lake volcanic belt (Kirkland, 1959). The major units strike northeast and dip to the northwest. Only one major fold is recognized and it is overturned to the southeast and plunges steeply northeast. The rocks that are derived from sedimentary material are represented by quartzo-feldspathic biotite gneisses, garnetiferous biotite migmatites, calc-silicate and hornblende gneisses, and granulites. These were intruded by basic and ultrabasic rocks and the resulting complex was then intruded by granitic rocks.

Lac la Ronge and Ile 'a la Crosse.--McLarty (1936a and b) and Frarey (1950a) have described these areas on a regional scale. The metasedimentary rocks are not unlike those described in areas to the north. Volcanic rocks are present but regionally they represent only a small part of the exposures. Considerable detailed mapping has been completed in this area, mostly in the eastern part of the Lac la Ronge area.

In the Settee Lake area (Budding, 1955; Morris, 1961) the dominant trends are very pronounced in a northeasterly direction. The volcanic rocks present are apparently a continuation of those occurring in the Waddy and Windrum Lakes area to the north and northeast and consist of both acidic and basic types. They are more extensive in the west half of this area (Morris, 1961), and in the northwest corner a series of biotite gneisses and granulites are thought to be younger than the metavolcanics and older paragneisses to the

southeast. This older complex consists of meta-arkose, quartz-biotite gneisses, quartz-biotite-hornblende gneisses, migmatites, and hornblende and calc-silicate gneisses. Garnetiferous members are common. The meta-sedimentary and metavolcanic rocks have been intruded by basic rocks including diorites which in turn are cut by granitic intrusions (Morris, 1961).

The volcanic belt described above continues to the southeast where it has been mapped in the Forbes Lake area (Pearson and Froese, 1959). Here it consists mainly of different types of basic volcanics with lesser amounts of acidic material. The regional fabric is about N.50° E. and is locally disrupted by large ovoidal-shaped masses of granite. The metasedimentary rocks are very similar to those occurring in the Settee Lake area and consist of biotite gneisses and granulites, interlayered hornblende and calc-silicate gneisses, and migmatites. Minor basic intrusions composed of diorite, meta-gabbro, and meta-pyroxenite occur throughout the area. A variety of acidic to intermediate intrusions cut the older rocks and later basic dikes are present. Most of the dips are to the northwest and since isoclinal folding is present, this indicates overturning to the southeast.

The volcanic belt continues to the southeast to the Otter Lake area (Padgham, 1960) where rock types and relations to the basic and acidic intrusions are the same as those to the northwest at Forbes Lake. In the northern part of the area the strikes of banding and foliation are at about N.60° E. and dips are mostly to the northwest. A deviation from the typical northeast structures occurs in the southern part of the area where regional strike is northerly. Faults trend northeast in the northern part and just slightly west of north in the southern part. Isoclinal folding is suggested (Padgham, 1960).

Essentially no volcanic rocks are present in the Trout Lake area just west of the Otter Lake area (Morris, 1960). At least two-thirds of the area is underlain by intrusions ranging in composition from acidic to basic. The metasediments are similar to those described above. Lineaments which are probably faults strike northerly (Morris, 1960) parallel to the dominant trend of the rocks. Some northeast trending structures are present in the most northerly part of the area.

In the Stanley area to the south metavolcanics form only a minor part of the area. Mawdsley and Grout (1951, p. 8) think that the metasediments originally consisted of sediments with compositions ranging from . . . "sandstone, generally impure, through mudrocks to pure limestones." As in the previously discussed areas most of the rocks are granites; mixed assemblages of schists, gneisses, and granites; and schists and gneisses of high metamorphic grade. In this area there is evidence for two ages of granites (Mawdsley and Grout, 1951, p. 15-16).

From the descriptions of McLarty (1936a and b) and Frarey (1950a) the rocks in the remaining parts of the Lac la Ronge and Ile 'a la Crosse areas seem to be similar to those described in the areas where mapping has been more detailed. A belt of metavolcanics has been mapped in the western part of the Lac la Ronge area but there is some doubt regarding the origin of these rocks (Money, 1962, personal communication).

Pelican Narrows (West Half).--The rocks of the most north-westerly corner of this area have the typical northeast trends but further south there is a suggestion of some northwest trending belts although structures are complex (Taylor, 1958a). Approximately half of the exposures are granite, granodiorite, quartz diorite, and pegmatite. Taylor (1958a) thinks that the

granitic rocks are partly intrusive and partly granitized and possibly two ages are present. Gneisses and schist derived mainly from sediments form the bulk of the remaining rocks. Hornblende-rich rocks, commonly garnetiferous and gneissic, occur associated with metamorphosed quartzite, arkose, and greywacke. Staurolite and sillimanite schists, undoubtedly derived from pelitic rocks, are locally common. Minor stocks of gabbro and pyroxenite were emplaced prior to the regional metamorphism and were extensively converted to amphibolites. Kirkland (1957) and Budding and Kirkland (1956) have mapped adjacent areas straddling the Tabbernor Lake fault. Their work has been incorporated by Taylor (1958a).

Porter Lake-Haultain River.--Alcock, Sproule, and Downie (1941a and b) mapped this area. The rock types and relationships here are not appreciably different than those in the main part of the northeast-trending gneissic belt to the east. Northeast structures are represented mainly by belts of gneissic rocks. The metamorphic rocks of sedimentary parentage consist of biotite and biotite-garnet gneiss and schist, quartzite, argillite, and calc-silicate rocks. Mafic gneisses for the most part of igneous origin occur mainly in the southeast quarter of the Porter Lake area where they appear to outline broad open folds or domal structures (Alcock, Sproule and Downie, 1941a and Alcock, 1935).

Weitzel Lake-Brustad River-Upper Clearwater River-Firebag River.--The rocks here are much the same as those occurring to the south (Sproule, 1941; Sproule and Downie, 1941; Ellis, Downie and Sproule, 1941). Two linear belts of metavolcanics mantled with wide bands of granitized schists and gneisses trend northeast. The eastern band in the Brustad River area (Sproule and Downie,

1941) consists of andesite with some rhyolite, and hornblende and chlorite schists with some granitic intrusions. The western band is somewhat different in that it consists of gabbro and anorthosite, diorite and diorite gneiss, andesite and schistose andesite (Ellis, Downie, and Sproule, 1941). The authors of this map sheet, however, think that the two bands of intrusive and volcanic rocks may be correlative and the present outcrop pattern is the result of a synclinal fold. In the Weitzel Lake area uralitic diabase cuts the Athabasca series (Sproule, 1941) and hornblende from this diabase gives a K-Ar date of 1.23 b.y. (table 17).

The far western part of the area is partially covered with glacial drift. Outcrops are sparse and little is known of the regional structure. Tremblay (1961) has identified the main rock types as garnetiferous gneisses and associated granitic rocks. Basaltic dikes and sills may be post-Athabasca in age. Blake (1956b) has noted a marked similarity between rocks of this area and those occurring in the Oldman River area to the north of Lake Athabasca.

Summary, Regional Correlations, and Dates.--The map-areas discussed have some remarkable regional similarities which can be summarized as follows:

(1) Pronounced uniform northeast structures as evidenced by orientation of metasedimentary belts, and banding, foliation, and gneissosity within these belts. Isoclinal folding is common and overturning to the southeast is evident in places.

(2) A variety of sedimentary-derived rock types are present but certain types appear to be most prevalent. Derivatives of impure clastic sediments, especially arkoses, are widespread and fairly pure quartzites are present in places. Argillites and their derivatives are not uncommon and calcareous rocks are widespread although not in great amounts. Mafic gneisses occur

interbanded with the paragneisses and probably represent both volcanic rocks and impure calcareous sediments. Garnet is a common mineral in many of the gneisses and diopside, tremolite, cordierite, sillimanite, and staurolite are locally important. Hornblende and biotite are ubiquitous metamorphic minerals.

(3) Invasion by granitic rocks has been accompanied by widespread, usually high grade, metamorphism, granitization and feldspathization. As a result of this migmatites are a common rock type.

(4) Most of the mafic intrusions are thought to have been emplaced prior to the main period(s) of metamorphism and are generally altered. Locally late diabasic dikes and sills occur.

In general the rock types present in the paragneisses and paraschists are suggestive of a shelf or miogeosynclinal environment of deposition. Metavolcanics are present, but generally in amounts subordinate to other rock types. The main greenstone belts occur in the vicinity of Waddy Lake and in the Brustad Lake area. It may or may not be significant that these two belts occur essentially on either side of the main gneissic belt. More detailed mapping may confirm this speculation or point out a more widespread distribution of eugeosynclinal deposits which perhaps have not been recognized because of the high grade of metamorphism.

Only a few attempts have been made to correlate the rocks of this area with those of adjacent areas. In the Oliver Lake area Alcock, (1939) noted the resemblance of the metasedimentary and metavolcanic rocks to the Wekusko group of Manitoba. McLarty (1936a and b) also related metasedimentary and metavolcanic rocks of the Lac la Ronge area to the Wekusko group. Mawdsley and Grout (1951) are in favor of retaining the name Lac la Ronge series for these rocks, a name applied by McInnes in 1909. All of the units except the

Athabasca series and later diabase dikes have been classed as Archean during the course of reconnaissance. This classification is obviously based on degree of metamorphism and has little significance with regard to their true age.

Several K-Ar dates on feldspars are available from Middle Foster Lake area (Mawdsley, 1957b) but these are unreliable because of probable argon leakage. Collins et al (1954) report a uraninite date from Lac la Ronge, apparently from a pegmatite, as 1.74 b.y. More recently the Geological Survey of Canada has dated several micas from the area (Lowden, 1961). The dates obtained and general locations are as follows:

Wollaston Lake area, sillimanite gneiss	1.67 b.y.
Porter Lake area, paragneiss	1.65 b.y.
Ile 'a la Crosse area, paragneiss	1.55 b.y.
Lac la Ronge area, pegmatite	1.71 b.y.
Pelican Narrows area, biotite granodiorite	1.63 b.y.

Money (1962, personal communication) has dated mica and hornblende from six samples in the Eulas Lake area about 60 miles northwest of Lac la Ronge. Four mica dates average 1.72 b.y. and two hornblende dates are 1.87 b.y. The latter two are somewhat older than previously obtained for this area.

The available dates are consistent with those obtained during the present study from basement rocks to the south. The 1.7 b.y. mica dates are the result of the Hudsonian orogeny and give a minimum age for the metamorphosed rocks. The hornblende dates from Eulas Lake may indicate an earlier event and continuing work by Money will be of interest.

A speculative stratigraphic chart for the area as a whole is presented in table 3. It summarizes the probable relationships between the various metamorphic and igneous units, which occur throughout the area.

Table 3. Regional Stratigraphy of Area II

Middle Proterozoic	Uralitic diabase (1.23 b.y.)		
	----- Intrusive Contact -----		
	Athabasca series		
	===== Unconformity =====		
Lower Proterozoic or older	Diabase (may be post-Athabasca)		
	----- Intrusive Contact -----		
	Varieties of granite, granodiorite, quartz diorite etc. [Very likely of more than one age]		
	 (Intrusive in part)		
	(Gradational in part)		
	Paragneisses and schists, granitized and feldspathized rocks, migmatites with varying proportions of igneous and metamorphic components.		
	 Gradational		
	Basic Intrusives		
	- - - Intrusive contact - - -		
	Metasediments and higher grade metamorphics derived mainly from:		
	Arkoses and impure quartzites	Relationship not clear	Waddy-Windrum Lakes section
	Quartzite		Conglomerate & metasediments
	Argillite		===== Unconformity =====
	Minor conglomerates		Granite (?)*
	Limestones and impure limey rocks		- - - Intrusive - - -
	Greywackes		Metavolcanics
	Minor associated volcanic rocks		Metagreywackes and associated metasediments
	?		?

* Evidenced only by granitic boulders and cobbles in conglomerate.

AREA III

For purposes of discussion this area is divided into two parts. The first lies north of latitude 57 degrees and the geology is not too well known. The second area includes the Lynn Lake and Flin Flon regions and the intermediate area underlain by Kisseynew gneisses and granites.

Harrison (1951a) has summarized the literature and discussed in detail the various correlation problems of the Precambrian rocks of Manitoba with special reference to the Kisseynew gneiss problem. Much recent work has been done by both the Geological Survey of Canada and the Manitoba Mines Branch. The publication of preliminary map sheets covering much of northern Manitoba has facilitated the development of a regional picture of an area which not long ago was practically unknown territory as shown by the Geological Map of Manitoba (Canada Geol. Survey, 1946).

Northern Manitoba.--For this discussion the area is terminated at the south by latitude 57 degrees north. No maps are available north of latitude 59 degrees. The map sheets of the area on a scale of one inch to four miles include the following: Whiskey Jack Lake, Brochet, Big Sand Lake, Northern Indian Lake, and Shethanei Lake. These are discussed briefly in the order given.

Currie (1961a) has mapped the Whiskey Jack Lake area which lies adjacent to the Wollaston Lake area of Saskatchewan. The southeast corner of the area and lesser parts elsewhere are covered with glacial debris and relations are poorly known. A significant structural feature is the change in direction of folding. In the northwestern and western parts, structures are complex but there is a northeasterly trend. These trends are undoubtedly a continuation of the very pronounced northeasterly trends of adjacent parts of Saskatchewan. Along the Seal River folds in the metasediments trend easterly.

Curie (1961a) also notes two directions of major faulting: N. 80° W. and N. 45° E. These directions are also common in the northeasterly trending gneissic belt of Saskatchewan.

The rocks of the area are composed mainly of paragneisses, in places partially granitized, and varieties of granite which underlie about 60 per cent of the area. Biotite-plagioclase schist and garnet-cordierite and plagioclase-cordierite gneisses pass gradationally into more quartz-rich gneisses. Lime-silicate rocks containing diopside and tremolite occur in minor amounts. The quartzose rocks include biotite and hornblende gneisses, hybrid gneiss and migmatite, and some quartzite. A complex of basic rocks includes amphibolite schists and sheared hornblendites. Remnants of basic intrusions occur in this unit.

Gadd (1950) mapped the Brochet area south of the Whiskey Jack Lake area. Swamp and glacial debris cover much of the area. Structures are complex as shown by the structural trends. Gadd refers to the metasedimentary rocks as Kiseynew-type. This reference apparently is based on similarity of rock types and complexity of structures to the Kiseynew rocks south of Lynn Lake area. The paragneisses are thought to have been derived from greywacke, arkose, and minor impure quartzite. Minor basic intrusions consist of gabbro and anorthosite. Diorite and quartz diorite have been mapped in the northwest and southeast corners of the area. Granitic intrusive rocks, the major unit, comprise 50 per cent of the rock types. These are variable in composition and texture but the most common phase consists of porphyritic, pink or grey granite. Feldspar phenocrysts up to two inches long are common, and some up to five inches long have been noted. A few hypersthene granites and granodiorites were observed in the main granitic masses.

More than half of the northern part of the Big Sand Lake area is drift covered (Quinn, 1960a). Banding and foliation trends in the southern part of the area are mainly easterly. Quinn (1960a) has identified a strong set of linears striking north-northeast, which he thinks are probably large joints or dikes. Hornblende-plagioclase gneiss derived from volcanic rocks forms a small band in the southern part of the area and is characterized by sulphide mineralization. Garnetiferous gneiss and schist, minor quartzite, and metaconglomerate comprise the metasedimentary unit but occurrences are limited. One of the main units is a group of mixed gneisses consisting of sedimentary, volcanic, and granitic material. Granite gneiss, the major unit, is variable in all aspects and commonly contains inclusions of older material. Gradations between the granite gneisses and the mixed gneisses are common. Mafic intrusive rocks consist of diorite, basic syenite, gabbro, pyroxenite, peridotite, and serpentinite.

Outcrops in the Northern Indian Lake area are extremely limited and approximately 90 per cent of the area is drift covered (Kretz, 1959). The main outcrops occur in the western part of the area in the vicinity of the Churchill River and Northern Indian Lake. Of the seven units differentiated during the course of mapping, one is composed of schist, gneiss and amphibolite; one is a mixed unit of gneiss, amphibolite, and granitic rocks; and the remaining five are acidic to intermediate igneous rocks. Kretz (1959) thinks most of the igneous-looking rocks were formed by replacement. Little is known about the regional structure but there does appear to be a predominance of easterly strikes, although variations exist.

Taylor (1958b) mapped the Shethanei Lake area lying to the north of the Northern Indian Lake area. The main outcrops are along the Seal River in the northern part of the area and along North Knife Lake and North Knife

River in the central and southern parts. In the northeast corner of the area a group of moderately folded, unmetamorphosed sedimentary rocks overlies unconformably older rocks composed of metasediments, metavolcanics, gneisses, and granitic rocks. From the limited evidence the older belts appear to trend in an easterly direction. Both massive and gneissic granitic rocks are distinguished. Gradations have been noted from metasediments through paragneiss to gneissic and massive granite.

The younger group of sedimentary rocks have been named the Great Island group, consisting of unaltered arenaceous, argillaceous, and dolomitic and calcareous rocks. Folding has occurred and the main structure is a syncline plunging steeply north. These rocks are cut by diabasic dikes and quartz veins but none of the granites in the area are thought to be younger than the Great Island group.

Biotite from a gneissic quartz monzonite has been dated at 1.63 b.y. (Lowdon, 1961). Because all of the granitic rocks are thought to be older than the Great Island group, this date represents a maximum age for the group. It is worthy of note that the stratigraphic position of the Great Island group in relation to a probable 1.6 to 1.8 b.y. old basement is similar to the Athabasca series to the west and perhaps to the Hurwitz group to the north, although in the latter case the basement may be older. Dating of one of the post-Great Island group dikes would help bracket a time interval for these sedimentary rocks.

Lynn Lake-Flin Flon.--This area includes the belt of volcanic and sedimentary rocks of the Lynn Lake area, the high-grade Kiseynew gneiss belts and intervening granitic complex, and the Flin Flon belt of volcanic and sedimentary rocks. The regional structures or trends of belts appears to

be in an easterly direction although the structures within the belts are complex. The Lynn Lake belt of volcanics and sediments is restricted in occurrence to Manitoba but the Flin Flon belt extends some distance into Saskatchewan. The Kiseynew complex underlies a large area and is thought to extend from the Tabbernor Lake fault on the west to somewhere near the Nelson River valley on the east (Quinn, 1955), and may have a total length of 250 miles (Harrison, 1951a).

The rocks and stratigraphic relations in the two volcanic-sedimentary belts are similar and have been called Keewatin-Timiskaming types. The Kiseynew gneisses on the other hand have been compared with the Grenville gneisses both in terms of composition and complexity of structure. Granitic rocks are intimately associated with the paragneisses, which in part have been derived from shaley, sandy, and limey sediments. Mafic gneisses have been interpreted as both volcanic and sedimentary in origin.

The distribution of the Lynn Lake belt of volcanic and sedimentary rocks is shown by Downie (1936); Henderson, Norman, and Downie (1936); and on a more regional scale by Rice (1953). The most recent study of the area is by Milligan (1960). To the north of this belt the rock types are similar to those described in the Brochet area. To the south the Kiseynew gneisses are predominant. Milligan (1960) estimates a minimum thickness of 18,000 feet for the volcanic and associated sedimentary rocks of the Wasekwan series, the oldest unit of the area. Within the Wasekwan series Milligan has mapped eight units, but the main rock types consist of massive and pillowed andesitic and basaltic volcanic rocks. Overlying the Wasekwan unconformably is the Sickie series, composed of arkose, quartzite, slate, conglomerate, and derived schists.

Pre-Sickie--post-Wasekan intrusions include plutonic rocks which range in composition from acidic to ultrabasic. Acidic and intermediate rocks

are most abundant, but basic rocks are important because of associated mineralization. Post-Sickle intrusive rocks are variable, but mainly acidic in composition. A few late lamprophyre dikes are present in the Lynn Lake area.

The Kiseynew complex which lies to the south of the main exposures of Wasekwan and Sickle rocks is thought by Milligan (1960, p. 91) to have been formed by metamorphism of Sickle sediments. He notes several places where Sickle rocks grade into Kiseynew gneisses. The following rock types have been mapped in the Kiseynew gneisses of this area: muscovite-biotite schists, derived from arkose; plagioclase amphibolite, probably derived from lime-rich sediments; granitoid paragneiss; and quartz-plagioclase-hornblende-biotite gneiss (Milligan, 1960). The complexity of structure is shown on the Granville Lake map sheets (Downie, 1936; Henderson, Norman, and Downie, 1936). A large area underlain by granitic rocks occurs south of this northern belt of Kiseynew gneisses (Harrison, 1949a). Kiseynew gneisses have been mapped and described in the Wapus Bay area of Saskatchewan (Cheesman, 1959; Pyke, 1960).

The Uhlman Lake area has been mapped by Wright (1953). Granitic rocks underlie much of the area and more or less easterly trending belts of meta-sediments and metavolcanics and derived gneisses occur. Wright (1953) notes that these may be correlative with the Sickle and Wasekwan series to the west. Burwash (1962) has recently completed detail mapping in the Rusty Lake area (fig. 5) where Wasekwan, Sickle and Kiseynew-type rocks occur as well as two ages of intrusions.

In Saskatchewan, Byers and Dahlstrom (1954) mapped the Amisk-Wildnest Lakes area. Other areas in Saskatchewan pertinent to the present discussion have been mapped by Byers (1957), Cheesman (1956), Kirkland (1958), and Pyke

(1961). In Manitoba the most recent maps on a scale of one inch to one mile include those of Armstrong (1941), Bateman and Harrison (1945, 1946), Buckham (1944), Frarey (1950b), Harrison (1949b), Kalliokoski (1952), McGlynn (1959), Robertson (1953), Stanton (1947), and Tanton (1941a and b). The Pas map sheet (Wright, 1934b) gives a regional picture of the area although it is outdated somewhat by the great amount of newer data.

The general geology is remarkably similar to that of the Lynn Lake area. An older unit of basic volcanic rocks and lesser amounts of associated sedimentary rocks is overlain unconformably by a younger sedimentary series. The older unit is called the Amisk group and the younger, mainly sedimentary unit, the Missi series. Both post-Missi and pre-Missi--post-Amisk granitic intrusions occur, although there has been some argument concerning the relative ages of these granitic rocks. Lying north of this volcanic-sedimentary belt are the southern exposures of Kiseynew gneisses. The relationships of the Kiseynew and Amisk-Missi rocks are not clear at all places, and there appears to be contradictory evidence as to their relations.

The Amisk group is dominated by basic lavas with lesser amounts of silicic-volcanic and sedimentary rocks. The Missi series is composed of arkose, greywacke, quartzite, conglomerate, and their metamorphic equivalents. At Amisk Lake in Saskatchewan, a "quartz-eye" granite is thought to be post-Missi (Byers and Dahlstrom, 1954) whereas at Cliff Lake (fig. 7), Manitoba a similar granite is pre-Missi (Stockwell, 1946). In the Weldon Bay area, east of Flin Flon, Missi rocks are absent (Kalliokoski, 1952) and the same is true in the Elbow-Heming Lakes area, although some minor areas of sediments have not been classified (McGlynn, 1959). Amisk rocks occur in both of these as well as abundant post-Amisk intrusions. In the File-Tramping Lakes area Harrison (1949b) has mapped Amisk rocks but the post-Amisk sedimentary unit

is called the Snow group. Most of the Snow group rocks have undergone moderate to high grade metamorphism and appear to be gradational into the Kiseynew gneisses (Harrison, 1949b). In the Wekusko area, Armstrong (1941) mapped a series of metavolcanics and named them the Laguna series. In the adjoining area, Crowduck Bay, Frarey (1950b) maps Amisk rocks and a younger sedimentary series which he provisionally correlates with the Missi. Harrison (1951a) has suggested that the term Laguna be abandoned.

In general, this belt is characterized by the widespread occurrences of Amisk volcanic rocks. Younger Missi rocks appear to be more restricted and their main occurrence is in the Flin Flon area. Basic intrusions are present and two ages of granites occur.

The Kiseynew gneisses in the southern belt are similar to the gneisses occurring in the northern belt. Folding is typically complex in most area. Harrison (1951a, p. 40) thinks the original Kiseynew strata consisted of argillite, greywacke, arkose, and sandstone with local conglomeratic and limey facies. These were interstratified with basic lavas and pyroclastic rocks and the whole sequence was intruded by basic dikes and sills. The resulting assemblage has been subsequently metamorphosed and intruded thus developing a complex of paragneisses, migmatites, amphibolites, calc-silicate rocks, and granitic phases. In the Batty Lake area (Robertson, 1953), Kiseynew gneisses are divided into the Nokomis and Sherridon groups. This division is based on a distinctive change in sedimentation. The older Nokomis group becomes fine grained at the top and contains graphite. Discontinuous limestones and orthoquartzites then appear and grade into the overlying Sherridon group which is quartz-rich. Robertson (1953) thinks that the Nokomis rocks represent a geosynclinal environment with a fairly positive land area contributing material. At the end of Nokomis deposition the land area was

considerably lower and quartzose and limey rocks began to be deposited. On the basis of chemical analyses Robertson (1953) concludes that some of the Nokomis rocks represent altered greywackes. The rocks on which the analyses were done (Robertson, 1953, p. 13) are probably not greywackes but shales. Greywackes have compositions consistently similar to granodiorites, whereas Robertson's analyses are too high in alumina and show the wrong alkali relationship for greywackes. This doesn't alter his interpretation, as certainly some of the rocks described by him and also McGlynn (1959) could have been derived from greywackes.

The relationship of the Kiseynew complex to the rocks on the south has not been agreed on by all workers in the area. Harrison (1951a, p. 40-41) summarized the possible age relations as follows:

1. The Kiseynew gneisses are a complex of different ages, perhaps including Amisk and Missi rocks.
2. The Kiseynew gneisses are younger than Amisk and older than Missi.
3. The Kiseynew gneisses are younger than Amisk and equivalent to Missi.
4. The Kiseynew gneisses are of indeterminate relative age to the Amisk and Missi because of faulting.

In Saskatchewan a fault separates Kiseynew gneisses from the main body of Amisk and Missi rocks but Byers and Dahlstrom (1954) note that some Amisk and Missi rocks occur north of the fault. They believe the Kiseynew gneisses are the metamorphic equivalent of Amisk and Missi rocks.

In the Weldon Bay area Kalliokoski (1952) points out that Kiseynew gneisses are separated from the unit to the south by a fault, thus, stratigraphic evidence for correlation is lacking. However, on the basis of structural evidence he favors the theory that the Kiseynew rocks are younger than the Amisk rocks. He points out that the Amisk rocks have been folded twice and the Kiseynew folding is superimposed on the Amisk,

but the older Amisk folding is not reflected in the Kiseynew rocks. Kalliokoski (1953) in a later paper says that in most places the Amisk group is separated from the Kiseynew rocks by a fault, the Kiseynew lineament. He notes that evidence for a fault is lacking in places but attributes this to granitization, recrystallization, or later folding and faulting. In order to explain the distribution and structural attitudes of the Kiseynew gneisses occurring on either side of the granitic core, Kalliokoski (1953) postulates a tectogene mechanism. As the Kiseynew gneisses were compressed by north-south forces they were folded and overturned to the south and thrust over the Amisk rocks. The apparent northerly structures in the southern band of Kiseynew gneisses are explained by a plunge of fold axes to the east. When these easterly plunging recumbent folds were reduced to a horizontal plane by erosion, the traces of bedding and foliation resulted in an apparent series of north-trending structures.

Harrison (1951a) thinks it is hazardous to attempt correlation of the Kiseynew gneisses, although he does speculate on the possibility of the Kiseynew gneisses being the more off-shore facies of the Missi and Sickle rocks, which are regarded as continental deposits. This idea fits well with the data found at Lynn Lake where gradations have been observed between the Kiseynew and Sickle rocks.

Armstrong's (1960) idea is similar to Harrison's speculation and he suggests that the Kiseynew rocks and Amisk-Missi and Wasekwan-Sickle rocks were essentially contemporaneous and represent two different types of sedimentary environment. He visualizes a rather shallow basin of deposition for the Kiseynew rocks bordered on either side by volcanic archipelagos. The evidence found in Saskatchewan would favor this correlation (Byers and Dahlstrom, 1954).

Ages and Correlations.--The correlation of rocks of the Lynn Lake area with those of the Flin Flon area is open to a certain amount of criticism because of the intervening area of Kiseynew gneisses and granites. As Milligan (1960) points out in his discussion of correlation of the Kiseynew gneisses, the intervening band of granite complicates matters by making it impossible to prove correlation of the two bands of Kiseynew gneisses and even more difficult to prove the Amisk-Waskewan and Missi-Sickle correlations. Harrison (1951a), however, on the basis of similarity of rock types and stratigraphic succession, does believe the correlation is valid.

The correlation problems of the Kiseynew gneisses has been discussed. Evidence seems to be contradictory from place to place and it is impossible to make any all-inclusive statements concerning the correlation of these rocks. In the Lynn Lake area, evidence indicates Kiseynew-Sickle correlation; in Saskatchewan the Kiseynew gneisses grade into both Amisk and Missi rocks; in Manitoba structural evidence suggests a post-Amisk age for the Kiseynew rocks.

Elsewhere in northern Manitoba it is extremely difficult to attempt any correlation among the various rocks because of sparsity of outcrop and high grade of metamorphism in many places.

A number of K-Ar dates have been completed on samples from Manitoba, but so far they have not resolved many of the correlation problems. Table 4 shows these dates and the probable geologic age of the samples. The complete data for dates done at the University of Alberta are given in table 17. These and dates determined by other laboratories are plotted on figure 20.

All of the dates obtained so far range from 1.61 to 1.84 b.y. and can be expressed by an average value of 1.72 ± 0.12 b.y. This maximum range of seven per cent is more than generally assumed for analytical error.

Geologically the dates are from samples which are distinctly different in age. It is rather difficult to say with any degree of certainty whether the dates merely represent a normal scatter of one particular event or whether more than one event is involved. The oldest dates obtained on material with known geologic relations are 1.82 b.y. (AK 269) and 1.83 b.y. (AK 270), on pre-Sickle and pre-Missi intrusions respectively. These dates are on hornblende, and pre-Sickle (Missi) biotite dates are slightly younger. The dates on post-Sickle (Missi) intrusions, Sickle (Missi) gneisses, Wasekwan (Amisk) gneisses and Kiseynew gneisses are all very similar. Good examples are the muscovite (AK 257) and hornblende (AK 255) from the Rusty Lake area (fig. 5) which are both dated at 1.74 b.y. The muscovite-bearing granite is post-Sickle and the hornblende diorite is thought to be pre-Sickle in age (Burwash, 1962). This is suggestive that the post-Sickle metamorphism was widespread and of sufficient intensity to cause recrystallization or outgassing of biotite and, in places hornblende, formed during the pre-Sickle (Missi)--post-Wasekwan (Amisk) period of metamorphism.

Three possible interpretations are evident:

(1) All of the dates represent a post-Sickle and Missi regional metamorphism accompanied by igneous activity at about 1.7 b.y. ago.

(2) Most of the dates represent a post-Sickle and Missi event, but hornblende in pre-Sickle and pre-Missi granites has locally survived the metamorphism and the dates on these hornblendes indicate the time of intrusion and metamorphism which affected Amisk and Wasekwan rocks.

(3) The two hornblende dates mentioned in (2) are survival values from much older, perhaps Archean, rocks. According to this interpretation they formed much earlier than indicated and were partially outgassed during the 1.7 b.y. event.

Table 4.--Summary of K-Ar dates from northern Manitoba (Area III)

Lab. No.	Mineral	Rock Type	Geologic Age, Reference	Date (b.y.)	Source
Lynn Lake Area:					
AK 271	Bio.	Biotite granite	Cobble from Sickie Cong. (1)	1.73	This paper
AK 272	Hbl.	Amphibolite	Wasekwan series (1)	1.74	"
AK 269	Hbl.	Quartz diorite	Pre-Sickie series (1)	1.82	"
AK 255	Hbl.	Hornblende diorite	Pre-Sickie series ? (2)	1.74	"
AK 257	Musc.	Muscovite granite	Post-Sickie series (2)	1.74	"
B3812	Bio.	Granite	Pre-Sickie series (1)	1.70	MIT
B3875	Bio.	Paragneiss	Wasekwan series (1)	1.74	MIT
B3876	Bio.	Granite	Pre-Sickie series (1)	1.64	MIT
GSC60-75	Bio.	Schist	Wasekwan series (1)	1.61	GSC
GSC60-76	Bio.	Granitic gneiss	Pre-Sickie series (1)	1.66	GSC
GSC60-77	Bio.	Meta-arkose	Sickie series (3)	1.65	GSC
Northern Indian Lake Area:					
B3907	Bio.	Granite	(4)	1.74	MIT
B3910	Bio.	Granodiorite	(4)	1.72	MIT
B3915	Bio.	Paragneiss	(4)	1.80	MIT
GSC59-40	Bio.	Gneissic granodiorite	(4)	1.73	GSC
Shethanei Lake Area:					
GSC60-70	Bio.	Quartz monzonite	Pre-Great Island group(10)	1.63	GSC
Flin Flon Area:					
AK 270	Hbl.	Hornblende diorite	Pre-Missi series (5)	1.83	This paper
GSC60-72	Bio.	Quartz diorite	Post-Missi series (6)	1.73	GSC
GSC60-73	Bio.	Paragneiss	Kisseynew (7)	1.74	GSC
GSC60-74	Bio.	Granite	Post-Amisk group (8)	1.75	GSC
B3295	Bio.	Gneiss	Amisk ? (9)	1.76	MIT

Geologic Ages and References:

- | | |
|--|--|
| (1) Milligan (1960) | (6) Byers and Dahlstrom (1954) |
| (2) Burwash (1962) | (7) Bateman and Harrison (1945) |
| (3) Henderson, Norman, and Downie (1936) | (8) Stanton (1947) |
| (4) Kretz (1959) | (9) Armstrong (1941), and Harrison (1951a) |
| (5) Tanton (1941b) and Harrison (1951a) | (10) Taylor (1958b) |

Sources:

MIT, Moore, et al (1960)
GSC, Lowdon (1960, 1961)



POST-SICKLE INTRUSIONS



PEGMATITE, APLITE



PINK BIOTITE GRANITE

PORPHYRITIC
BIOTITE GRANITEHORNBLende-
BIOTITE GRANITE

KISSEYNEW-TYPE GNEISSES

PARAGNEISS
MIGMATITE
AMPHIBOLITE

SICKLE SERIES

MUSCOVITE-BIOTITE
SCHIST, BIOTITE SCHIST,
BIOTITE-HORNBLende
SCHISTQUARTZITE, MICACEOUS
QUARTZITE,
META-ARKOSE

CONGLOMERATE

PRE-SICKLE INTRUSIONS

BIOTITE-HORNBLende
TONALITEHORNBLende DIORITE
HORNBLende TONALITE
MINOR HORNBLende
GABBRO

WASEKWAN SERIES

HORNBLende-BIOTITE
HORNFELS, PLAGIOCLASE
AMPHIBOLITE, MINOR
QUARTZ-BIO. SCHIST AND
MICACEOUS QUARTZITEPYRRHOTITE-BEARING
TUFFHORNBLende SCHIST
(META-BASALT, META-
ANDESITE), PORPHYRITIC
BASALT

● SAMPLE LOCATION

GEOLOGY OF THE RUSTY LAKE AREA



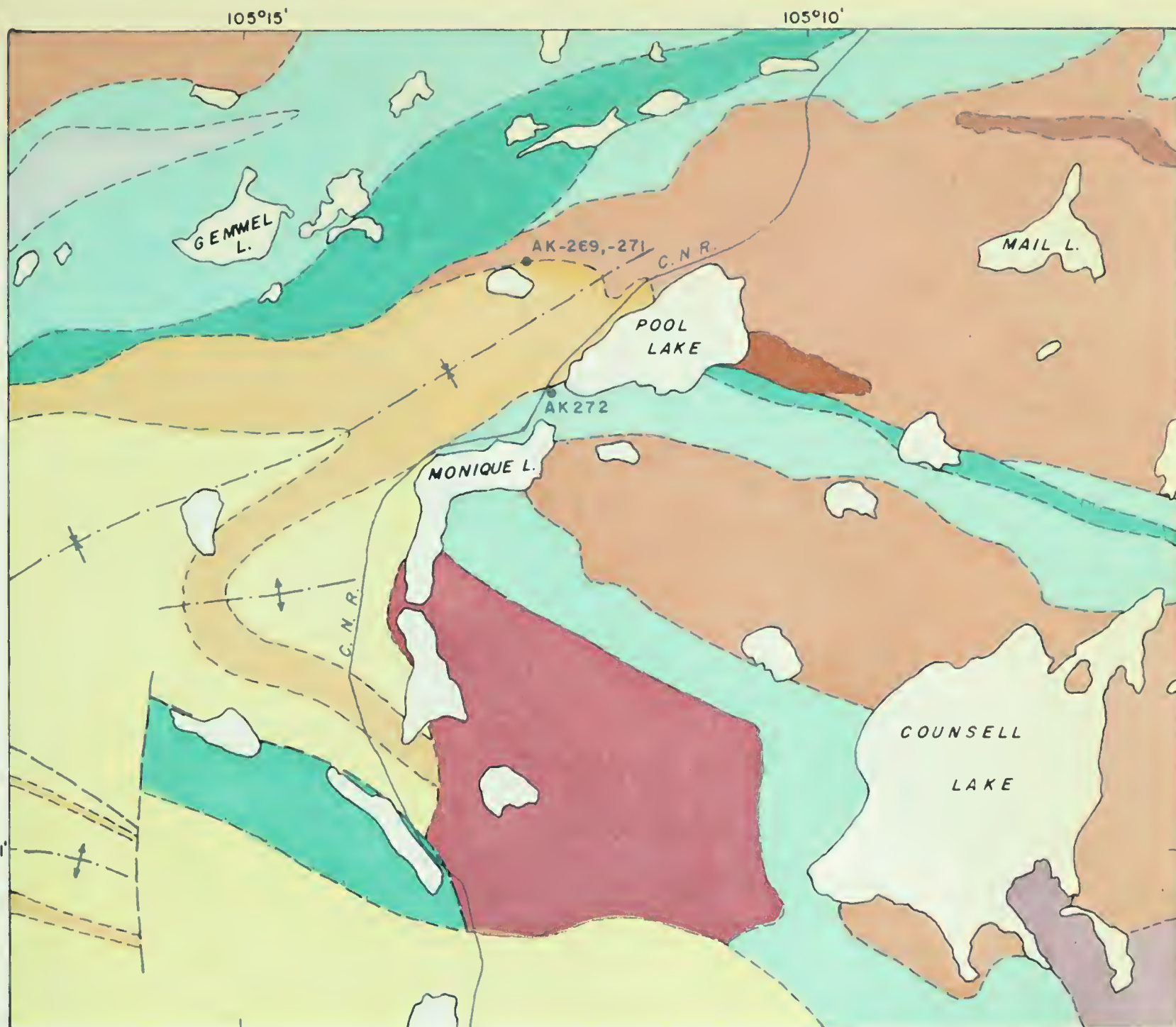
SCALE OF MILES

Figure 5.--Geology of the Rusty Lake area (after Burwash, 1962).

If the two older dates are survival values, then a more detailed look at the areas from which they were collected might be elucidating. The Lynn Lake sample (fig. 6) was taken from a pre-Sickle diorite near an exposure of Sickle conglomerate. Metamorphism of the area has been sufficient to produce hornblende of a 1.74 b.y. (AK 272) age in a Waskewan amphibolite (table 4). It is quite possible then that the hornblende in the diorite was either recrystallized or partially outgassed during this metamorphism.

The older sample from the Flin Flon area (fig. 7) was taken from the Cliff Lake granite, where metamorphism in the surrounding rocks has not been so extreme. The acidic phase of the granite is altered, as shown by the chloritization of the mafics and sericitization of the plagioclase, but it is not especially sheared. Considering the lesser degree of metamorphism in this area, it is possible that the 1.83 b.y. date on the Cliff Lake granite is real although the possibility that it is a survival value cannot be completely discounted.

A generalized correlation chart of this area is presented in table 5. Because of the 1.7 b.y. event, which appears to have affected most of the rocks of the area, all of the units except the Great Island group are at least Lower Proterozoic in age. If the two hornblende dates on pre-Missi and Sickle granites are real then the Missi and Sickle are restricted to the upper part of the Lower Proterozoic. If the dates are merely part of the 1.7 event, or are survival values of originally much greater age, then there is no evidence to indicate a maximum age for either the Missi and Amisk rocks or their equivalents to the north. It is possible, though perhaps not probable, that both the Missi and Amisk are Archean. However, it seems more likely that the Amisk is Archean and the Missi is Proterozoic.



GEOLOGY OF THE POOL LAKE AREA

0 1 2 MILES
SCALE

GREY HORNBLENE-BIOTITE
TONALITE AND GRANODIORITE

GABBRO AND HORNBLENDITE

WASEKWAN SERIES

PLAG. AMPHIBOLITE DERIVED
FROM ANDESITE AND BASALT
MINOR SEDIMENTS AND
PYROCLASTICS

INTERBEDDED VOLCANIC,
SEDIMENTARY AND/OR
TUFFACEOUS ROCKS

GREYWACKE, QUARTZITE, DERIVED
SCHISTS AND GNEISSES; SOME
UNDIFFERENTIATED PYROCLASTICS
AND FLOWS

FAULT
TRACE OF
FOLD AXIAL PLANE
• SAMPLE LOCATION

GRANITIC ROCKS OF
UNCERTAIN AGE

PINK AND GREY APLITIC GRANITE
AND GRANODIORITE; SOME
COARSER PHASES AND ALASKITE

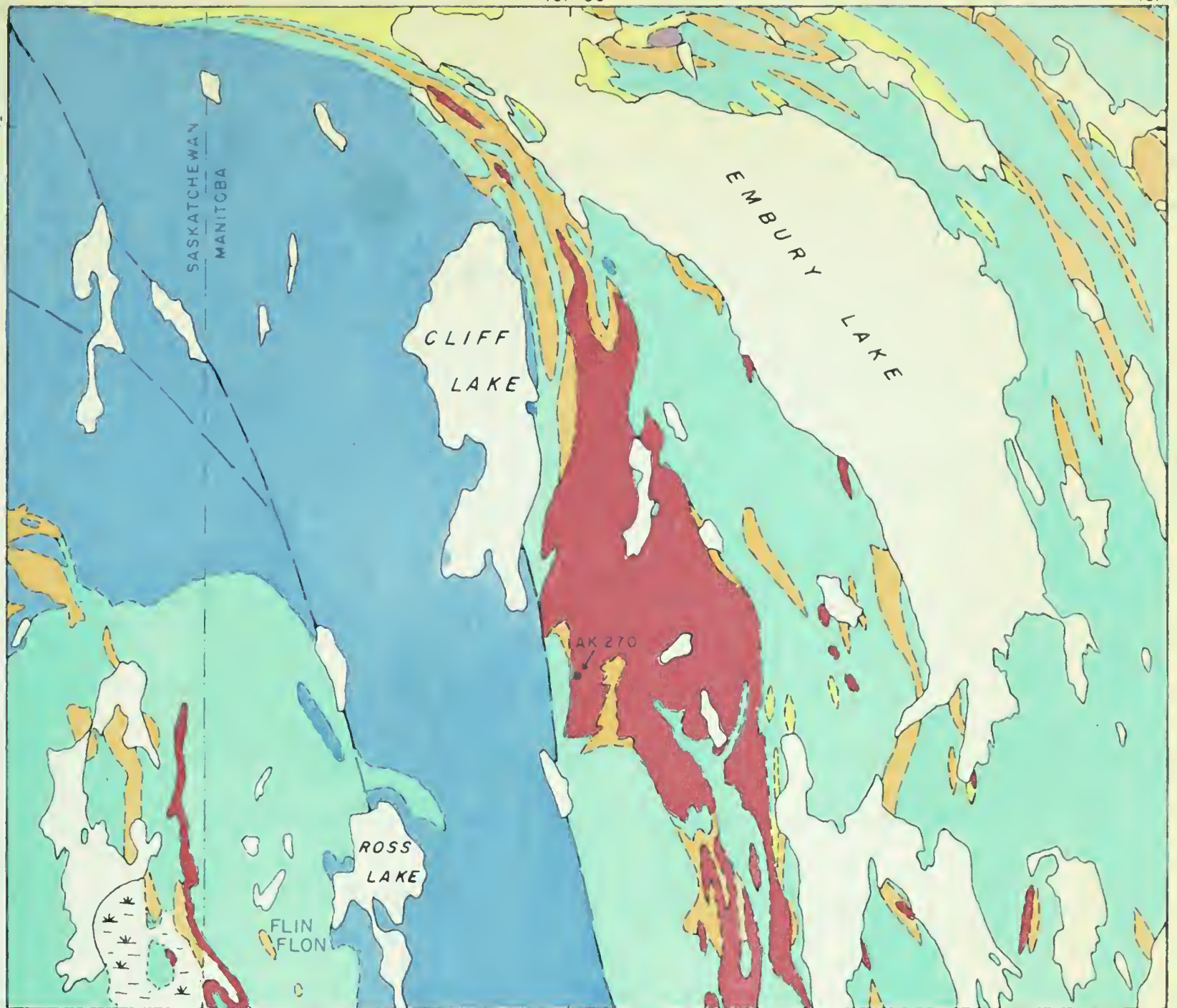
SICKLE SERIES

ARKOSE AND QUARTZITE,
FELDSPATHIC SANDSTONE,
SOME GREYWACKE

CONGLOMERATE; ARKOSE WITH
PEBBLE BEDS

UNCONFORMITY

Figure 6.--Geology of the Pool Lake area (after Milligan, 1960).



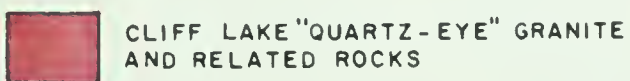
GEOLOGY OF THE FLIN FLON AREA



MISSI SERIES



UNCONFORMITY



AMISK GROUP



• SAMPLE LOCATION

Figure 7.--Geology of the Flin Flon area (after Tanton, 1941b).

Table 5.--Correlation chart for Area III

	Flin Flon	Lynn Lake	Northern Manitoba	
Middle or Upper Proterozoic		Basic dikes	Diabase dikes	
		- - - - - Intrusive Contact - - - - -		
			Great Island group (Shethanei area only)	
	= = = = = Unconformity = = = = =			
		Granite and allied rocks		
Lower Proterozoic (Archean ?)		<----- Basin intrusions ----->		
		(accompanied by widespread regional metamorphism)		
		- - - - - Intrusive and Gradational Contact - - - - -		
	Missi series	gneisses ?	Sickle series	
	= = = = = Unconformity = = = = =			
	"Quartz-eye" granite	Kisseynew	Granite and allied rocks Basic and ultrabasic intrusions	
			Relationship not clear	
				Variety of schists, gneisses, and migma- tites derived from sedimentary and volcanic rocks.
		- - - - - Intrusive contact - - - - -		
	Amisk group	Wasekwan group		

AREA IV

Harrison (1951a) referred to this area as the Thicket Portage region in his discussion of correlation problems in Manitoba. Wilson and Brisbin (1961) termed it the Nelson River gneissic zone. Physiographically the area is the Nelson River valley. The area is of special interest because it is thought that it contains the boundary between the Churchill and Superior geologic provinces. There are also important nickel deposits which make the area of economic interest.

J.T. Wilson (1949a) summarizes as follows the reasons for this area being chosen as the boundary between the two structural and age provinces.

- (1) The Nelson River valley is pre-Ordovician in age.
- (2) It is marked by gravity anomalies.
- (3) It appears to divide areas of different rock types, foliation trends, and types of mineralization.

The pre-Ordovician age of the Nelson River valley is shown by embayments of Ordovician sediments at both ends of the belt. The gravity anomalies are shown by Innes (1960b) and Wilson and Brisbin (1961). Structurally the Nelson River valley is thought to separate the easterly-trending structures of the Superior province from the northeast-trending structures of the Churchill province. This may be somewhat of a generalization as the more recent four-mile maps to the north indicate at least some easterly structures and the pronounced north-east trends which are thought to be typical of the Churchill province occur mainly in Saskatchewan.

The four-mile map sheets covering the area are Nelson House (Quinn, 1955), Sipiwesk (Harrison, 1951b), Split Lake (Mulligan, 1957), and Kettle Rapids (Quinn, 1961). Gill (1951a and b) mapped the Mystery Lake and Waskaiowaka Lake areas; information from the latter report is included on the

Split Lake map (Mulligan, 1957). Other studies of the area are mentioned by Harrison (1951a).

In general, the area is one of considerable deformation. Faulting and folding have been intense and more than one period of folding has been reported (Quinn, 1955). Many faults are recognized as well as a number of topographic linears, some of which are undoubtedly faults or fractures. Part of a 160 mile zone of faulting is exposed in the Nelson House area. This shear zone strikes about N. 30° E. and may join the Assean Lake fault to the north which strikes about N. 60° E. The Assean Lake fault probably extends along the Odei River and through Assean Lake, but evidence for continuation to the east in the Kettle Rapids area is lacking mainly because of extensive deposits of Pleistocene and Recent sediments. Basic and ultrabasic intrusions are typically associated with these major fault zones.

Dawson (1941) during his study of the Assean Lake area divided the stratified rocks into two units. A sequence of metasediments and metavolcanics, the Assean Lake group, appeared to overlies unconformably an older, more highly metamorphosed, complex of gneisses which he called the pre-Assean Lake group. Gill (1951a) in a restudy of the area, concluded that the pre-Assean Lake group of Dawson was actually just a more highly metamorphosed phase of the Assean Lake rocks. Mulligan (1957) is apparently in agreement with this idea. In the Nelson House area, Quinn (1955) considers the Assean Lake group to be the oldest unit and the higher grade gneisses are derived from this group. Harrison (1951b) in the Sipiwesk area separates the more highly metamorphosed sedimentary rocks from the Assean Lake group but notes that there is no evidence to indicate that the two units are different in age. More recently, Quinn (1961) has found structural evidence in the Kettle Rapids area to support the concept of an older pre-Assean Lake group.

In this area moderately metamorphosed arenaceous sediments with minor chert and limestone appear to transect the trend of the supposedly older more highly metamorphosed units. The problem is not resolved, but it appears in most areas that evidence for the presence of pre-Assean Lake group rocks is inconclusive.

The Assean Lake group consists of metamorphosed greywacke; argillite; quartzite; minor limestone, chert, conglomerate and iron formation; and associated volcanic rocks. This group appears to be commonly associated with the major zones of faulting (Quinn, 1955; Mulligan, 1957; and Harrison, 1951b). A variety of high-grade gneisses of both sedimentary and volcanic origin also occur in the vicinity of the faults, and, at least in some places, these are derived from the Assean Lake group rocks.

Two ages of granite have been mapped in most areas. The older is generally gneissic and in places shows gradations into the gneissic rocks derived from older sedimentary and volcanic rocks. The younger granites appear to be more massive. Harrison (1951b) and Gill (1951a) noted "quartz-eye" granites in places which are similar to the "quartz-eye" granites of the Flin Flon area. In Sipiwesk area hypersthene granites are present and examination of some samples during this investigation indicates they have typical charnockitic features and compositions.

Basic and ultrabasic intrusions also appear to be of two different ages. The older units are commonly associated with the shear zones and in places are appreciably altered. The younger intrusions are generally in the form of dikes. In the Sipiwesk area these dikes have a remarkably uniform strike at N. 30° E. It is interesting to note that this is the direction of the faults in the Nelson House area, suggesting that there is some relation. Table 6 gives a speculative chart of the rock units as

Table 6.--Stratigraphy of Area IV.

	Rocks	Probable Ages (b.y.)
	Diabasic dikes	Probably both >1.7 and <1.7
	- - - - -Intrusive contact- - - - -	
Lower Proterozoic	Massive granitic and associated rocks.	1.7 to 1.8
	- - - - -Intrusive contact- - - - -	
	Altered basic to ultrabasic rocks (peridotite, pyroxenite, gabbro, diorite, serpentinite)	>1.8 <2.4
	- - - - -Intrusive contact- - - - -	
Archean	Gneissic granitic and allied rocks (granite, syenite, granodiorite, monzonite, hypersthene granite, "quartz-eye" granite)	2.4 and older
	- - - - -Intrusive and gradational - -	
	<u>Assean Lake group</u> ; basic to intermediate volcanic rocks, quartzite, greywacke, arkose, conglomerate, argillite, minor chert, iron formation, limestone, and derived schists and gneisses.	>2.4
	= = = = =Unconformity (?)= = = = =	
	<u>Pre-Assean Lake group</u> ; * paragneisses and schists, greenstones, amphi- bolites, and associated basic dikes and sills.	>> 2.4

*Recognized now only in the Kettle Rapids area. Elsewhere either evidence is lacking for an unconformity (Harrison, 1951b), or it indicates transition from Assean Lake group rocks to those of higher grade (Gill, 1951a).

deduced from the various map sheets covering the area. The relationships shown seem to be consistent in most of the area, except for the presence of the pre-Assean Lake group in the Kettle Rapids area. Locally the late diabase is cut by granite but the reverse is also true (Harrison, 1951b).

The presence of intense faulting has been previously mentioned. In the Nelson House area, Quinn (1955) interprets the shear zones as representing thrust faults. Gill's (1951a) drag fold evidence indicates right-hand transcurrent movement for the Assean Lake fault although some vertical displacement is suggested. At Utik and Cross Lake, although some distance to the south of the Assean Lake fault, Wilson and Brisbin (1961) claim east-west bands of rock are turned through an angle of 135 degrees where the bands meet the gneissic zone of the Nelson River area. These relations could be interpreted as representing right-hand movement over the gneissic area as a whole, and therefore, the N. 60° E. faults would show right hand movement. In the Kettle Rapids area the banding and foliation of the older units strike essentially northwest whereas just to the south in the Knee Lake area the bands or belts trend slightly north of west. Since a projection of the Assean Lake fault would extend just north of the main outcrops in the Kettle Rapids area, this apparent swing of the belts to the northwest may be related to the movement of the Assean Lake fault. If this is so, right-hand movement is suggested.

Some of the linears occurring in various areas show uniform orientations suggesting regional fault or fracture systems. In the Sipiwesk area linears are very apparent. One of the more pronounced is the course followed by the Nelson River, which, after making a turn to the northeast near Sipiwesk Lake, follows a remarkably straight course for a distance of about 60 miles. This direction is very nearly parallel to the diabase dikes and

major thrust faults to the west. East of the Nelson River linear, a well-developed east-northeast drainage pattern occurs. The linears here strike about N. 60° E. and parallel the Assean Lake fault to the north. In the same area a few linears strike between 10 and 25 degrees west of north. In the Utik and Bear Lake areas known faults strike approximately easterly (Milligan, 1952). A rather pronounced linear extending from the Nelson River to Bear Lake is thought to be the extension of one of the known faults.

It is difficult to visualize a stress pattern that would explain all of the faults and linears. If the Assean Lake fault is actually a right hand transcurrent fault, deformation with the principle stress axis orientated in about an east-west direction would be indicated.

Eight K-Ar age determinations are available from this area (table 7). Six of the eight are in the range of 1.7 to 1.8 b.y. and two are about 2.4 b.y. This wide variance in age is not surprising when one considers the nature of a boundary area. There are certainly indications that the Hudsonian orogeny at about 1.7 b.y. had considerable effect on parts of the older Superior province. A similar situation was seen in the Northwest Territories but the "mixed-age" zone seems much wider there than is indicated here.

The two samples dated at the University of Alberta during the present investigation are from the same band of gneiss, mapped by Harrison (1951b) as pre-Assean Lake group (fig. 8). As mentioned before, he finds no evidence to indicate that they are of a different age than the Assean Lake group. Both the Assean Lake rocks and the more highly metamorphosed paragneisses are intruded by gneissic granite, a sample of which is dated at 2.40 b.y. (Lowdon, 1961). Biotite from the paragneiss mentioned above gives a date of 1.72 b.y. (AK 192) whereas hornblende from an associated mafic gneiss about one mile away gives a date of 2.41 b.y. (AK 256).

Table 7.--Summary of K-Ar dates from the Nelson River gneissic zone (Area IV)

Lab. No.	Mineral	Rock Type	Geologic Age, Reference	Date (b.y.)	Source
B3810	Bio.	Pegmatite	Post-Assean Lake group (1)	1.81	MIT
GSC60-79	Bio	Granitic gneiss	Post-Assean Lake group (2)	1.68	GSC
GSC60-81	Bio.	Augen gneiss	Assean Lake Group (3)	1.69	GSC
GSC60-82	Bio.	Paragneiss	(3)	1.72	GSC
GSC60-83	Bio.	Hyp. granite	Post-Assean Lake group (1)	2.40	GSC
GSC60-80	Bio.	Paragneiss	Pre-Assean Lake group (4)	1.78	GSC
AK 192	Bio.	Paragneiss	Pre-Assean Lake group (1)*	1.72	This paper
AK 256	Hbl.	Hyp.-hbl. gneiss	"	2.41	This paper

* AK 192 and AK 256 are from a unit mapped as pre-Assean Lake group by Harrison (1951b) but he notes that there is no evidence to indicate that the unit is not correlative with the Assean Lake group of the same area.

Geologic ages and References:

Sources:

(1) Harrison (1951b)

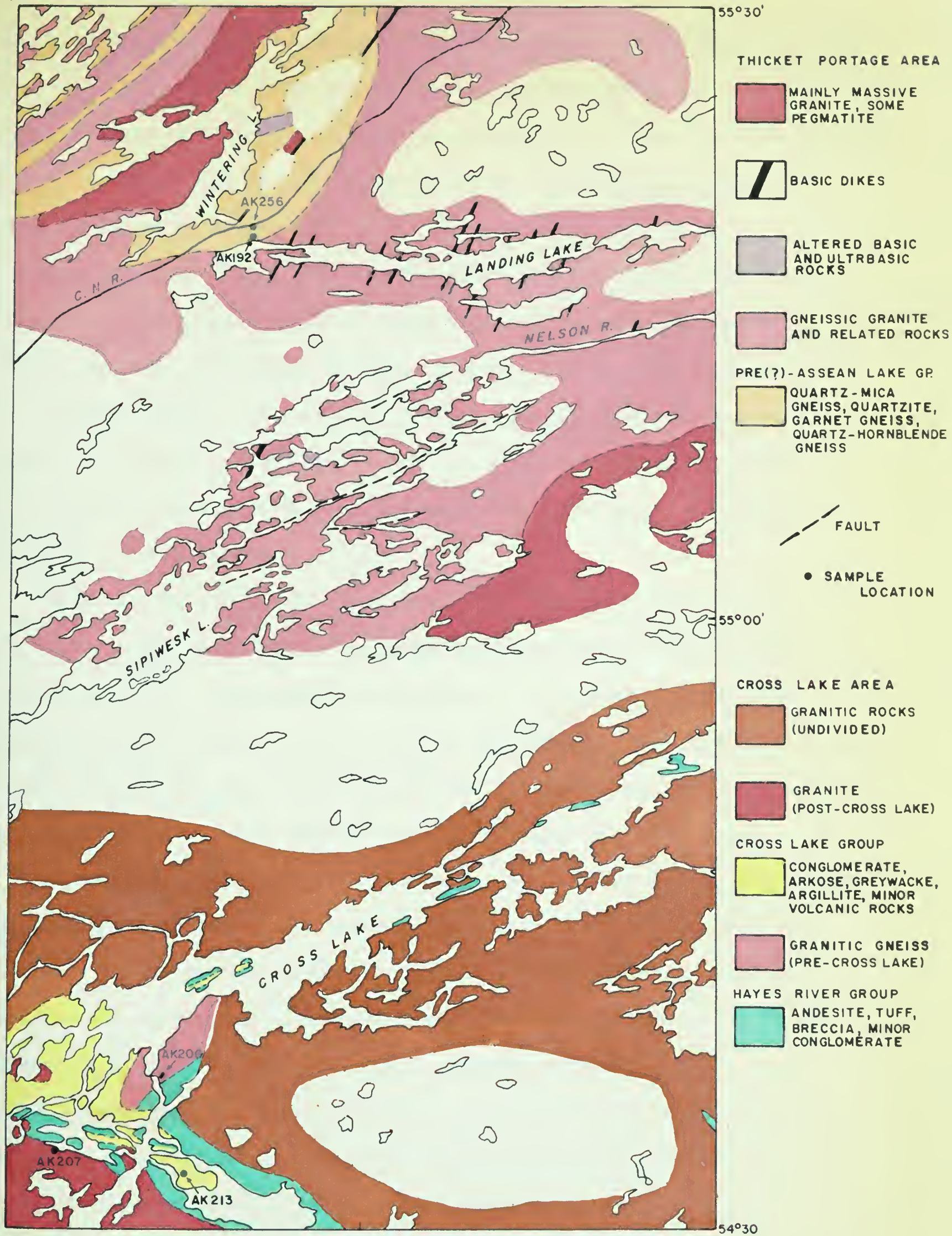
MIT, Moore et al (1960)

(2) Quinn (1955)

GSC, Lowdon (1961)

(3) Mulligan (1957)

(4) Quinn (1961)



GEOLOGY OF THE THICKET PORTAGE AND CROSS LAKE AREAS

0 4 8 12 16 MILES
SCALE

Figure 8.--Geology of the Thicket Portage and Cross Lake areas (after Horwood, 1935; Harrison, 1951b).

This relationship suggests that the Hudsonian orogeny was sufficient in this area to either recrystallize the biotite or at least drive off the accumulated argon, but not sufficient to affect the hornblende. Biotite from the gneissic pyroxene granite (Lowdon, 1961) apparently was not affected by the 1.7 b.y. event occurring to the north.

Near the Assean Lake fault in the Split Lakes and Kettle Rapids area biotites from paragneisses which may be Assean Lake group equivalents, and from a sample of Pre-Assean Lake rocks, gives dates of 1.69, 1.72, and 1.78 b.y. (Lowdon, 1961), respectively. In the Sipiwesk area, post-Assean Lake pegmatite is dated at 1.81 b.y. (Moore, et al, 1960) and in the Nelson House area, granitic gneiss which comes from a mixed gneiss assemblage is dated at 1.68 b.y. (Lowdon, 1961).

Assuming that the rocks mapped as Assean Lake group are everywhere correlative, the age relations as suggested by the K-Ar dates are shown in table 6. In this interpretation the dates on the probable Assean Lake group gneisses of about 1.7 b.y. would be attributed to the Hudsonian orogeny. If the gneissic granite unit is actually everywhere intrusive into the Assean Lake group an age greater than 2.4 b.y. is required for this group.

As mentioned previously one of the main reasons the Nelson River Valley was originally chosen as the boundary between the Churchill and Superior provinces is the associated gravity anomalies. These anomalies are well shown on the gravity map of Canada (Innes, 1960b) and the more recent map prepared by Wilson and Brisbin (1961). Linear representations of these anomalies are shown on figure 13. The most striking feature is the gravity low which coincides with the zone of greatest deformation and nickeliferous basic intrusions. Gravity highs occur more or less parallel to the low on either side. These anomalies can be traced to the southwest as far as the 49th Parallel, and possibly into North Dakota. Wilson and Brisbin (1961,

p. 817) consider the continuation of the gravity low to the southwest as delineating the position of the buried boundary between the Churchill and Superior provinces.

In order to explain the gravity anomalies associated with the Nelson River gneissic zone Wilson and Brisbin (1961, p. 819-820) invoke warping or folding at the base of the crust because the density distribution of the surface rocks does not explain the regional anomalies. The models proposed consist of a two-layer crust and the calculated anomalies agree well with those observed (Wilson and Brisbin, p. 820, figs. 6 and 7). The folding suggested involves amplitudes on the order of 8 miles at the Mohorovicic discontinuity and the width of the crustal fold belt is about 75 miles (op. cit, fig. 8).

On the basis of the gravity and geologic data Wilson and Brisbin (1961) draw an analogy between the Nelson River gneissic zone and modern island arcs. They postulate (p. 818) that the gneissic zone is . . . "the remnant root of a mountain range that extended as a great arc or double arc more than 500 miles stretching from near Hudson Bay to the United States Border The range may have been a continental boundary with the seaward side to the northwest or may have been a continental range like the Himalayas with old shield area in front."

AREA V

This area is referred to by Harrison (1951a) as the Gods, Island, and Oxford Lakes region. It comprises the shield area of Manitoba bounded on the north by the Nelson River gneissic zone and on the south by an area dominated by granitic rocks. For purposes of discussion the southern boundary is arbitrarily taken at 53 degrees north latitude. The areas which have been

mapped on a four-mile scale are: Knee Lake (Quinn, 1960b), and Norway House (Johnston, 1938a and b). The Cross Lake area has been mapped by Horwood (1935). Considerable work in the area has been completed by the Manitoba Mines Branch, some of which will be mentioned later. For a complete review of the literature prior to 1951 the reader is referred to Harrison (1951a).

The Geological Map of Manitoba (Canada Geol. Survey, 1946) shows the regional geologic setting of the area. Elongate belts of associated meta-volcanic and metasedimentary rocks trend easterly and are separated from one another by terranes dominated by granitic rocks. Generally within each belt, metasedimentary and metavolcanic rocks form separate mappable units. In most places an unconformity is thought to separate the older metavolcanic rocks from the younger metasedimentary rocks, and two ages of granitic rocks have been recognized locally. There are three areas in this main region in which stratigraphic relations are best known and these are discussed individually; the Gods-Knee-Oxford Lakes area recently mapped in some detail by Barry (1959, 1960, 1961), the Island Lake area, and the Cross Lake area.

Gods Lake-Knee Lake-Oxford Lake.--These areas are covered by the Oxford House (Wright, 1934a; Currie, 1961b) and Knee Lake (Quinn, 1956) four-mile maps. The oldest rocks consist mainly of basic volcanics and lesser amounts of associated metasedimentary rocks and basic intrusions. The younger, metasedimentary unit is composed mainly of arenaceous sedimentary rocks, conglomerates, and their metamorphic derivatives. Numerous acidic to intermediate granitic rocks are present as well as mixed or hybrid gneisses. Altered basic intrusions, late diabase, gabbro, and lamprophyre dikes are present. The older volcanic unit is called the Hayes River group and the overlying sedimentary unit, the Oxford group.

Barry (1961) and Dix (1948) mapped the Gods Lake area on a scale of one mile to the inch. In one area Barry (1961) determined a minimum thickness of 20,000 feet for the Hayes River group. The main rock types in this area consist of massive and ellipsoidal lavas with lesser amounts of volcanic breccia, tuff, and tuffaceous sediments. Gabbro, diorite, and amphibolite bodies are typically associated with this group. In the Oxford Lake and Knee Lake area Barry (1959) has divided the Hayes River group into two units; the lower unit contains mainly basic flows and associated basic intrusions, and the upper unit consists of a higher proportion of sedimentary material, volcanic breccias, and tuffaceous rocks but it is somewhat variable in composition from place to place (Barry, 1959, p. 13-18). In the western Oxford Lake area, Barry (1960) describes the same two-fold classification of the Hayes River group and the comprising rock types are similar to those described above.

Overlying the Hayes River group are sedimentary rocks belonging to the Oxford group. An unconformity separates the Oxford group from the Hayes River group and in places evidence for an intervening period of granite emplacement has been noted. Greywacke, subgreywacke, arkose, quartzite, argillite, iron formation, chert, conglomerate, and derived schists are typical rock types found in the Oxford group (Barry, 1959, 1960, 1961). The Oxford conglomerate is basal, at least in some areas, and carries cobbles and boulders of volcanic rocks derived from the older Hayes River group. In addition granitic cobbles are common in the conglomerate, even in areas where an older granite has not been identified. Numerous "quartz-eye" granite cobbles occur in the Oxford conglomerate at Gods Narrows and these are identical with the "quartz-eye" granite which is thought to be pre-Oxford in age. The Oxford group is typically folded but metamorphism has generally been only moderate.

Intrusive rocks of the area are varied in composition and texture. As mentioned previously, the Hayes River group has associated with it many basic intrusions, mainly in the form of sills. The post-Oxford intrusions range in composition from ultrabasic to acidic but the intermediate and acidic members are the most prevalent. Stratigraphically the pre-Oxford--post-Hayes River group "quartz-eye" granite is important. At Gods Narrows this granite appears to be related to feldspar and quartz porphyries which, in the form of dikes, extensively intrude the Hayes River group. Two lines of evidence indicate that the "quartz-eye" granite is pre-Oxford in age: (1) abundance of identical rock types as boulders in the basal Oxford conglomerate, (2) apparent lack of the related feldspar and quartz porphyries in the Oxford group whereas they are quite abundant in the Hayes River group. The evidence for the pre-Oxford age of this intrusion is circumstantial but nevertheless convincing. In other parts of the area the granitic boulders and cobbles in the Oxford conglomerate (Barry, 1959, 1960) certainly suggest the presence of a pre-Oxford granite even though none has been recognized. Late diabase, gabbro, and lesser lamprophyre dikes intrude many of the rocks of this area (Quinn, 1956; Currie, 1961b). They appear to be much more numerous in the Knee Lake area than the Oxford House area.

Island Lake.--This area is separated from the Gods-Knee Lake-Oxford Lakes area by a terrane of mainly granitic rocks with some linear belts of greenstone. The stratigraphic sequence is similar, however, and the oldest unit consisting of metavolcanic and associated metasedimentary rocks is correlated with the Hayes River group. Quinn (1960b) has divided the Hayes River group of this area into two units. The lower unit consists mainly of metavolcanic rocks ranging in composition from basic to

acidic, associated metasedimentary and pyroclastic rocks, and derived schists. The upper unit, which he notes may belong in part to the younger sedimentary group consists mainly of arenaceous metasedimentary rocks, conglomerate, minor metavolcanics, and derived schists.

The overlying metasedimentary unit was apparently first named the Island Lake series by Wright for the exposures in the vicinity of Island Lake (Harrison, 1951a). This sequence consists of arkose, arkosic quartzite, and conglomerate which forms a mappable unit up to 6000 feet in thickness (Quinn, 1960b). Graded bedding, crossbedding, scour and fill, ripple marks, and compaction structures have been identified in the finer-grained phases of the Island Lake series.

Intrusive rocks range in composition from ultrabasic to acidic and are of more than one age. The basic and ultrabasic rocks, except the late diabases, are typically associated with the volcanic unit of the Hayes River group, a relationship which was also noted to the north in the Oxford House and Knee Lake areas. Granitic rocks of more than one age occur in addition to later dikes of aplite and pegmatite. There is no direct structural evidence for a pre-Island Lake granite, however, Harrison (1951a) in his summary of the area says that pebbles of granite are common in the Island Lake conglomerate, indicating that an older granite was exposed during the Island Lake sedimentation.

Faults are major features of the area and the main fault zone extends across the northern part of the area covered by the Island Lake sheet (Quinn, 1960b). The regional strike of the fault is easterly although in the vicinity of Island Lake it swings to the southeast for some distance then resumes an easterly orientation. Quinn (1960b) suggests that the fault is a major thrust and notes the association of serpentized ultrabasic rocks.

West of Island Lake is the Norway House area, which has been mapped by Johnston (1938a and b). The western half is mapped as essentially all granite. In the east half a greenstone belt that appears to be a continuation of the Island Lake greenstone-sedimentary belt is exposed. Much of the area south of Island Lake is swamp covered, forming a reasonable southern limit to the area of discussion.

Cross Lake.--Horwood (1935) mapped the Cross Lake area but the map was published on a small scale (Horwood, 1935, fig. 1, p. 141). The metavolcanic rocks have been correlated with the Hayes River group. The correlation seems sound as the metavolcanic belts have been traced from the Oxford House area. Lithologically the Hayes River group of the Cross Lake area consists of thick series of andesitic lava flows, conglomerate, tuff, breccia, and iron formation--a sequence similar to that described to the east except for the conglomerate. The overlying metasedimentary unit has been named the Cross Lake series and is composed of conglomerate, arkose, argillite, and minor metavolcanic rocks. The conglomerate contains numerous boulders and cobbles of tonalite.

The main thesis of Horwood's paper (1935) is the suggestion that a large part of the area is underlain by pre-Keewatin (Hayes River) tonalite. The evidence for this is the presence of tonalite cobbles in both the Hayes River and Cross Lake conglomerates. More recently, however, Harrison (1951a) re-interpreted Horwood's evidence and suggests that the tonalite is a product of granitization and intrusion and is much younger than the Hayes River group. If this suggestion is true the tonalites would still be pre-Cross Lake in age because of the tonalite boulders in the conglomerate. Post-Cross Lake intrusions are mainly massive granites and associated aplitic and granitic dikes. Horwood's (1935, p. 142) modal analyses of some of these rocks show their potash-rich composition.

In summary, Area V is characterized by east erly trending belts of older metavolcanic rocks (Hayes River group) and younger metasedimentary rocks (Oxford group, Island Lake series, Cross Lake series). Indirect evidence in most areas suggests the presence of at least two ages of granitic rocks. Harrison (1951a) correlates the Hayes River group, and Oxford group and its equivalents, with the Amisk and Missi rocks of the Flin Flon region. This correlation transects the boundary between age provinces and therefore is hazardous. The Hayes River and Oxford groups are truly Archean (>2.4 b.y. old), but the Amisk and Missi rocks may be Lower Proterozoic (1.7 to 2.4 b.y. old).

The K-Ar age determinations available from this area are given in table 8. Some of the dates are considerably lower than those usually found in the Superior province. Moore et al (1960) attribute this to the proximity of the Churchill province to the north. They state . . . "A younger bordering orogeny will expose rocks from depth in which low grade metamorphism of varying degrees has developed a heterogeniety that may be broad or very local in scale." (Moore et al, 1960, p. 227). In the Oxford Lake area they interpret their 2.20 b.y. date as representing a partially affected sample of Superior rocks with an original age of 2.4 to 2.6 b.y. This same interpretation could be applied equally well to dates of 2.19 and 2.07 b.y. to the west (fig. 20). A date of 2.08 b.y. (AK 213) on a cobble from the Cross Lake conglomerate can also be considered a survival value and here the geologic evidence is convincing for such an interpretation. At Cross Lake, Rousell described the field relations of the samples which were dated during the present investigation (personal communication, 1961). The Cross Lake conglomerate overlies unconformably a gneissic complex dated at 2.50 b.y. (AK 206). About four and one-half miles from this sample (fig. 8) the conglomerate is intruded by granite dated at 1.84 b.y. (AK 207). A cobble

Table 8.--Summary of K-Ar dates from Cross Lake-Knee Lake-Gods Lake-Island Lake (Area V)

Lab. No.	Mineral	Rock Type	Geologic Age, Reference	Date (b.y.)	Source
B3808	Bio.	Gneissic granite	Post-Oxford group (1)	2.20	MIT
B3809	Bio.	Granite	Post-Oxford group (1)	1.64	MIT
AK 205	Bio.	Gneissic grano- diorite	Post-Oxford group (2)	2.38	This paper
AK 208	Bio.	"Quartz-eye" granodiorite	Pre-Oxford group--post- Hayes River group (2)	2.62	This paper
GSC60-85	Bio.	Quartz monzonite	(3)	2.19	GSC
GSC60-84	Bio.	Paragneiss	(4)	2.07	GSC
AK 206	Bio.	Biotite gneiss	Pre-Cross Lake group (5)	2.50	This paper
AK 207	Bio.	Granodiorite	Post-Cross Lake group (5)	1.84	This paper
AK 213	Bio.	Quartz diorite	Cobble in Cross Lake conglomerate	2.08	This paper

Geologic Ages and References:

Sources:

(1) Currie (1961b), Wright (1934a)

MIT, Moore et al (1960)

(2) Barry (1961)

GSC, Lowdon (1961)

(3) Johnston (1938a)

(4) See Lowdon (1961, p. 50)

(5) Rousell (1960, personal communication)

from the conglomerate resembling the older gneissic complex was collected about one and one-half miles from the contact of the conglomerate and younger granite. Biotite from this cobble gives a date of 2.08 b.y. (AK 213). The relations here then are quite clear. Gneissic rocks about 2.5 b.y. old contributed boulders to a younger conglomerate which was subsequently folded, metamorphosed, and intruded by granite at 1.8 b.y. The metamorphism accompanying the late granite intrusions was sufficient to partially outgas biotite in a boulder about one and one-half miles away from the contact. The younger granite appears to be definitely related to the Hudsonian orogeny, the main loci of which was the Churchill province to the northwest. The younger granite at Knee Lake dated at 1.64 b.y. (Moore, et al, 1960) probably has a similar origin.

Two dates completed during the present investigation from Gods Lake area are worthy of note. The relationships of the granites dated to the Oxford and Hayes River group are known (fig. 9). The pre-Oxford group "quartz-eye" granite gave a date of 2.62 b.y. (AK 208) and the post-Oxford group granite, a date of 2.38 b.y. (AK 205). If these differences in ages are real, the age of the Oxford group is determined within close limits for Precambrian stratigraphy.

A generalized stratigraphic chart for the three main areas is shown in table 9, and the K-Ar ages from table 8 are used where applicable. In general the K-Ar dating has suggested the presence of Proterozoic granites in the area. These were apparently accompanied by local heating effects which caused the updating of some of the Archean rocks. If the Churchill-Superior boundary is taken at the Assean Lake fault zone and the shear zone which passes through Setting Lake with a strike of N. 60° E., the Hudsonian orogeny affected a rather wide zone of older Superior rocks. The 1.64 b.y. old granite in the Knee Lake area is about 120 miles from the Assean Lake fault, and the Cross Lake samples are about 40 miles from the Setting Lake fault zone.

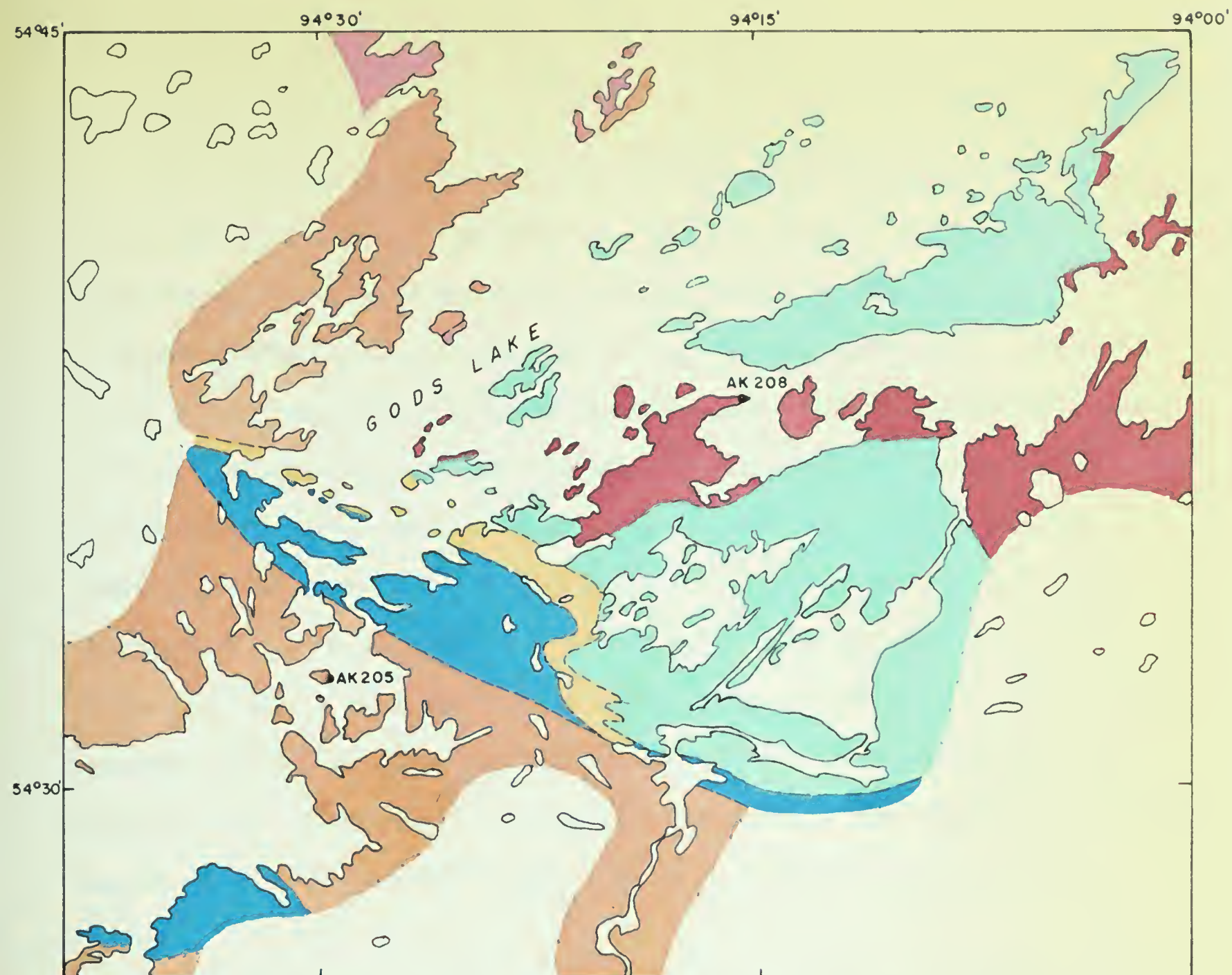
Table 9.--Correlation chart for Area V.

Dates (b.y.)		Cross Lake	Gods Lake-Knee Lake- Oxford Lake	Island Lake
Lower Proterozoic	1.84, 1.64	Biotite granodiorite and potassic granites	Granite	
		- - - - -	Intrusive contact - - - - -	
		< - - - - -	Diabasic dikes*- - - - -	>
		- - - - -	Intrusive contact - - - - -	
	2.38	< - - - - -	(Granite and allied rocks, Basic intrusions)	>
Archean		- - - - -	Intrusive contact - - - - -	
		Cross Lake series**	Oxford group	Island Lake series
		= = = = =	Unconformity = = = = =	
	2.50, 2.62	Tonalite***	"Quartz-eye" granite	Granite***
		- - - - -	Intrusive contact - - - - -	
		< - - - - -	Hayes River group of mainly metavolcanic rocks and associated basic intrusions.	>

* Relation to youngest granites not known. Diabase dikes are mapped as youngest intruions in all areas, which if true, implies an age for some of less than 1.7 b.y.

** The K-Ar dating in the Cross Lake area restricts the Cross Lake group to an age interval of 2.50 to 1.84 b.y. and does not preclude a Lower Proterozoic age for these rocks. Correlation with the Oxford group is based on lithologic and stratigraphic similarities.

*** Presence suggested by cobbles in overlying conglomerates.



GEOLOGY OF GODS LAKE

0 4 8 MILES
SCALE



MASSIVE PORPHYRITIC GRANITE

● SAMPLE LOCATION

GRANITIC GNEISS COMPLEX
PARAGNEISS AND ORTHOGNEISS

OXFORD GROUP

FINE GRAINED CLASTIC SEDIMENTS
AND DERIVED SCHISTSCONGLOMERATE WITH
BEDS OF ARKOSE

UNCONFORMITY



"QUARTZ-EYE" GRANODIORITE

VOLCANIC BRECCIA, TUFF, SEDIMENTS, BASALT,
ANDESITE, DACITE, MINOR RHYOLITE (INCLUDES
BASIC INTRUSIVE ROCKS)

Figure 9.--Geology of Gods Lake (after Wright, 1934a; Barry, 1961)

AREA VI.

The shield of Manitoba south of 53 degrees latitude north comprises the area of discussion. The area from about 51 degrees to 53 degrees latitude north is composed mainly of different types of granitic rocks (Johnston, 1938c,d,e,f,g), and most of the work has been concentrated south of this dominantly granitic terrane where two belts of metavolcanic and metasedimentary rocks are exposed. The northern belt extends in a west-northwest direction from the vicinity of Gem Lake on the east to Wanipigow Lake land beyond to the west. The southern band occurs in the vicinity of the Oiseau River and trends in an easterly direction. The Geological Map of Manitoba (Canada Geol. Survey, 1946) shows the regional geologic setting of these two "greenstone" belts. Harrison (1951a) has discussed the stratigraphy and reviewed the previous work of the area in some detail, and the following summary is taken mainly from Harrison's review.

The oldest rocks of the area consist of metavolcanic and metasedimentary rocks named the Rice Lake group. In some areas the sedimentary phase seems in part to be older than the volcanic phase, but in other areas the reverse situation has been noted. Wright (1932) describes the lithology of the Rice Lake group in the type area, and the following rocks have been identified: basalt, andesite, diabase, dacite, rhyolite, greywacke, quartzite, arkose, slate, chert, conglomerate, and derived schists and gneisses. Elsewhere the Rice Lake group is composed of similar rock types although in varied amounts.

Basic and ultrabasic rocks are intrusive into the Rice Lake group in both the northern and southern belts. These were apparently emplaced prior to the main period of granite invasion as they are generally altered and have undergone the same folding as the Rice Lake group (Stockwell and Lord, 1939). Later basic dikes have been noted in places.

A variety of granitic to intermediate intrusive rocks occur in the area and all are thought to be younger than the Rice Lake series. Granitic cobbles in a Rice Lake conglomerate were apparently derived from an older granite but it has not been recognized.

In the vicinity of Rice Lake, Stockwell (1938) discovered the presence of a post-Rice Lake series of sedimentary rocks and named these the San Antonio formation. This formation consists mainly of feldspathic quartzite and conglomerate. The relations of the San Antonio formation to the older rocks are shown on the Rice Lake map sheet (Stockwell, 1945a).

Several of the proposed stratigraphic relations for the area are shown by Harrison (1951a, table V, p. 25) and the section proposed by Stockwell (1938) has apparently been accepted as the standard. This stratigraphic section is essentially reproduced as table 10, along with age determinations where applicable to the stratigraphy.

A number of age determinations are available from this area although none were completed during the present investigation. The most recent are K-Ar ages by the Geological Survey of Canada (Lowdon, 1960, 1961). Gast, et al (1958) determined several dates by both K-Ar and Rb-Sr. Previous to this much work had been done on uraninite and monazite from pegmatites in the Oiseau River belt of rocks. These results have been summarized by Cumming, et al (1955), and Eckelmann and Kulp (1957).

Even though the area is well into the Superior province, on the order of 300 miles from the supposed Churchill-Superior boundary (fig. 20), the dates obtained by the various methods show some anomalous features. The U-Pb dates on uraninite and monazite from the Huron Claim are discordant and Eckelmann and Kulp (1957) postulate lead removal at some time in the past to explain the discordancies. They suggest a provisional

Table 10.--Stratigraphy of Area VI.

	Rock Units	Ages
Archean or Lower Proterozoic	Diabasic dikes (?)	
	- - - - -Intrusive contact- - - - -	
	San Antonio formation:* conglomerate, arkose, and quartzite	>1.7 b.y.
	= = = = = Unconformity = = = = =	
	Granitic and allied rocks including "quartz-eye" granite	2.4-2.6 b.y.
Archean	- - - - -Intrusive contact- - - - -	
	Basic to ultrabasic intrusions	
	- - - - -Intrusive contact- - - - -	
	Rice Lake group: metasedimentary and metavolcanic rocks	

* Harrison (1951a) in his comparisons with the Flin Flon section notes that in southeastern Manitoba it is difficult to prove the existence of a younger (post-San Antonio) granite whereas in the Flin Flon region the difficulty is proving the existence of an older (pre-Missi) granite.

age of 2650 ± 100 m.y. for the age of the pegmatite from which the minerals came. This is a minimum age for the Rice Lake group because of intrusive relations. Gast, et al (1958) on the basis of a concordia plot suggest that the event which caused the discordancy occurred 500 m.y. ago. They also suggest that the same event could have been responsible for some of the anomalies in the Rb-Sr and K-Ar determinations from this area. Gast, et al (1958) summarized their own and other Rb-Sr and K-Ar determinations from the area; seven Rb-Sr dates range from 2.20 to 2.52 b.y., whereas seven K-Ar dates are somewhat lower and range from 2.03 to 2.51 b.y. They conclude that the absolute age of the pegmatites in this area is 2.49 b.y. (2.65 b.y. using their decay constants).

Five K-Ar dates have recently been reported (Lowdon, 1960, 1961). Two dates of 2.67 b.y. were obtained on correlative granodiorites and these are thought to give a minimum age for the Rice Lake group and a maximum age for the San Antonio formation. To the north a younger granite is dated at 2.44 b.y. Biotite from a paragneiss, unit 5 on the Gem Lake map sheet (Stockwell, 1945b), gives a date of 1.70 b.y. The interpretation of this date is that it represents a younger period of metamorphism and granitization (Lowdon, 1961, p. 54). The 1.70 b.y. date is thought to represent a minimum for the San Antonio formation because both it and the Rice Lake group appear to have undergone similar folding (Lowdon, 1961, p. 54). A lepidolite from the Silver Leaf claim gives a date of 2.48 b.y. which is in the range reported by Gast et al (1958).

At the present time the assignment of the 1.70 b.y. date to a specific period of metamorphism and granitization in this area seems somewhat hazardous considering the other age determinations by the U-Pb, Rb-Sr, and K-Ar methods. As mentioned before, Eckelmann and Kulp (1957) postulate a general heating

of the area to account for apparent lead loss of the uranium minerals and Gast, et al (1958) have suggested that this heating occurred about 500 m.y. ago and this event may have caused some of the discrepancies in ages determined by the Rb-Sr and K-Ar methods. Therefore, before the 1.70 b.y. date can be taken to prove a "Hudsonian" event in this area it should be shown that the date is real and not just a partially outgassed sample of Superior-age material. One factor in favor of the 1.70 b.y. date representing an actual event is the absence of any known 500 m.y. event anywhere in the surrounding area, or in the Canadian shield as a whole. It may be argued that this 1.70 b.y. event was the cause of the Pb- loss and other discrepancies in the dates obtained so far. If this be true, Gast, et al (1958) are wrong in their interpretation of the time of lead loss.

AREA VII.

The Precambrian geology and geochronology of Minnesota has recently been described by Goldich, Nier, Baadsgaard, Hoffman, and Krueger (1961) and the following brief résumé is taken mainly from their publication. Some of the dates determined by these authors are plotted on fig. 20. These are generalized results representing many K-Ar and Rb-Sr determinations. Minnesota is endowed with rocks representing all of the presently known subdivisions of the Precambrian of the Canadian shield, and because of this and the proximity of the area to the basement of Manitoba and North Dakota the area is critical to the present study. As a result of geologic and intensive geochronologic investigations, Goldich, et al (1961) propose the following Precambrian classification for Minnesota.

Era	System	Orogeny	Dates (b.y.)
Late Precambrian	Keeweenawan	Grenville	1.0
- - - - -	- - - - -	Penokean	1.7
Middle Precambrian	Huronian		
- - - - -	- - - - -	Algoman	2.5
	Timiskamian		
Early Precambrian	- - - - -	Laurentian	> 2.6 =
	Ontarian		

Early Precambrian rocks occur mainly in northern Minnesota. The Ontarian system is represented by the Ely greenstones and associated Soudan iron formation in Minnesota and correlative metavolcanic and associated rocks in the adjacent parts of Ontario where they are referred to as the Keewatin group. Lying beneath the Keewatin rocks is a group of metasedimentary rocks and paragneisses called the Coutchiching. Since this group was originally defined (see Lawson, 1913) in the Rainy Lake area there has been much controversy with regard to their relation to Keewatin rocks. Recent work in the type locality (Yardley et al, 1959) has upheld Lawson's original conclusion regarding age. The Coutchiching is a valid stratigraphic unit consisting mainly of metamorphosed greywackes and pelitic sediments and it predates the Keewatin group of greenstones and associated rocks. In Minnesota, rocks of similar age may be represented by the Northern Light gneiss and the Burntside gneiss (Goldich, et al, 1961, p. 66-67).

At the end of Ontarion time granitic plutons were emplaced during the Laurentian orogeny. At Rainy Lake these Laurentian intrusions are represented by sheared and altered tonalites (Frye, 1959). An excellent example of such an intrusion occurs at Saganaga Lake where the geologic age can be determined precisely. Here the Saganaga "quartz-eye" granite is intrusive

into Keewatin greenstones and Northern Light gneiss and the resulting complex is in turn overlain by Timiskamian metasedimentary rocks of the Knife Lake group. In the Rainy Lake region the Seine conglomerate and arkose, correlatives of the Knife Lake group, also overlie Keewatin, Coutchiching, and Laurentian granites. The Knife Lake group is composed of greywacke, slate, conglomerate and some volcanic rocks. The Seine series has a similar composition less the volcanic members. Both the Knife Lake and Sein conglomerates contain boulders and cobbles of the older rocks including Laurentian granites, a fact which lends support to the stratigraphic interpretations.

Early Precambrian time was ended by the Algoman orogeny, the geological manifestations of which are the many Algoman intrusions. This orogeny corresponds to the Kenoran orogeny and was both extensive and intensive in northern Minnesota. The Giants Range and Vermilion batholithic igneous and metamorphic complexes were formed during the Algoman orogeny at approximately 2.5 b.y. ago. Some of the Algoman plutons in the Rainy Lake area are late kinematic in relative orogenic age, and have been dated at about 2.4 b.y.

During Middle Precambrian time the economically important Biwabik and Gunflint iron formations of the Animikie group were deposited. Other Animikie formations are the Pokegama quartzite, Virginia and Rove slates, and the Thomson formation comprised of greywacke and slate. These rocks were deposited at the margins or flank of the older Superior nucleus. At about 1.7 b.y. ago the Penokean orogeny ended the Middle Precambrian Era and the Animikie rocks were folded, metamorphosed to varying degrees, and intruded by granitic rocks. Most of the Penokean granites occur in central Minnesota and in the Minnesota River valley. The Hudsonian orogeny recognized in Canada corresponds to the Penokean orogeny of Minnesota.

Late Precambrian time is represented by a variety of rock types in Minnesota. The Sioux quartzite of southern Minnesota covers considerable area and appears to form a sizeable block of the basement in South Dakota. (See Steece, 1961). Most of the Late Precambrian rocks crop out in central and northeastern Minnesota where Keweenawan volcanic rocks cover a large area along the north shore of Lake Superior. These are associated with the intrusive rocks of the Duluth and related complexes emplaced at about 1.1 b.y. The youngest of the Late Precambrian rocks are the essentially flat-lying and unaltered Fond du Lac and Hinckley sandstones, sometimes referred to as the Red Clastic series.

The structural elements of northern Minnesota, are typical of the Superior province and strike nearly easterly or in places somewhat north of east. The regional trend of the iron formations is east-northeast.

The location of the basic intrusive and extrusive rocks of Late Precambrian age in Minnesota may be of regional structural significance. Gravity data suggests that a major basement rift may occur from central Kansas north-eastward possibly as far as Hudson Bay (Innes, 1960a, p. 319). This postulated fracture of continental proportions supposedly developed in Late Precambrian time, and perhaps tapped the source and formed the zone of weakness for the basic intrusions of which the Duluth gabbro and associated rocks are representative.

The structural trends of Minnesota likely persist into the basement of eastern North Dakota, and similar rock types are probably present there. The Animikie iron formations strike east-northeast and a projection westward would lie in South Dakota. The Penokean fold belt appears to be correlative in time and quite likely a continuation in space of the Churchill province of Canada. The boundary is taken at the contact between the Early Precambrian

rocks and the Animikie group. It is not known how much of the geosyncline in which Animikian rocks were deposited was floored by older Superior rocks. The dates obtained on the rocks from the southeast end of the Minnesota River Valley are about 2.4 b.y. and are therefore related to the Algonian orogeny (Goldich et al, 1961, p. 134). These dates are significant with regard to the southern extension of the pre-Animikian basement. At the northwestern end of the Minnesota River valley some rocks have been dated which yield ages between 1.7 and 2.5 b.y. These may be survival values, and indicate the approximate position of the boundary between the Superior nucleus and the Penokean fold belt.

AREA VIII.

The Little Rocky Mountains are the result of one of the many Tertiary intrusions of Montana. The intrusive syenite porphyry has caused a rather complicated system of domal structures and in places nearly circular faults (fig. 10). Stratigraphically the area is of interest because the uplift and subsequent erosion has resulted in the exposure of a complete section of the sedimentary rocks of this area of the plains. The fact that Precambrian rocks have been exposed makes the area of special interest to this investigation.

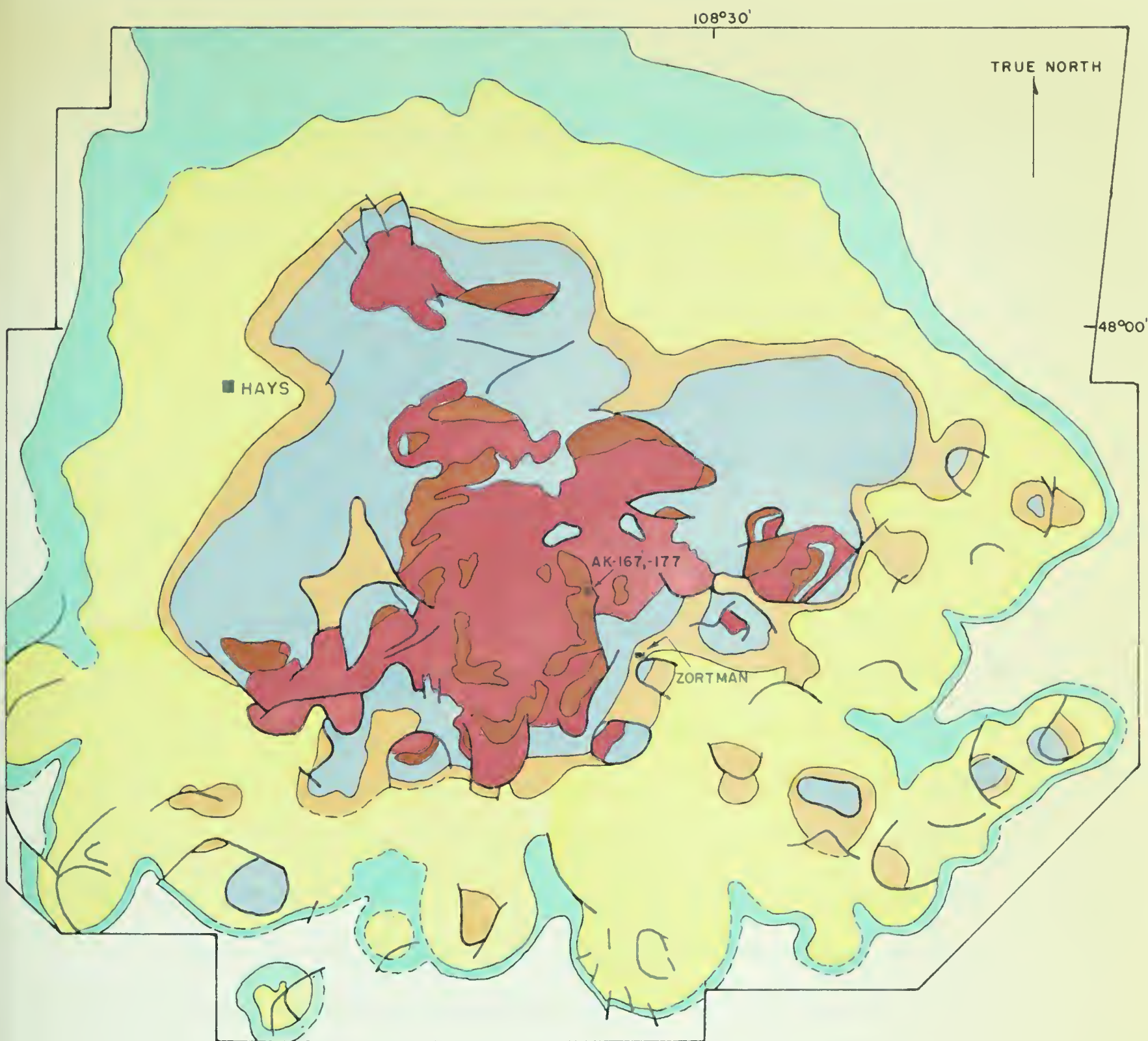
A recent comprehensive report on the area is available (Knechtel, 1959). The Precambrian rocks have been considered pre-Belt in age because of their metamorphism in the amphibolite facies. The main Precambrian rock types exposed are biotite schists and gneisses, quartzites, and amphibolites.

Biotite (AK 177) from a porphyroblastic biotite schist and hornblende (AK 167) from a quartz-feldspar-hornblende gneiss were dated (fig. 10). The dates obtained are 1.75 b.y. and 1.71 b.y. respectively (See table 17).

These suggest metamorphism during the Hudsonian orogeny. The samples from which biotite and hornblende were separated occur in adjacent outcrops where essentially flat-lying schists and gneisses are interlayered.

Knechtel (1959, p. 743) notes that . . . "these bodies of igneous rocks (syenite porphyry) represent alkalic magmas that invaded the Precambrian rocks--and possibly also the Cambrian rocks of some localities--but are believed to have solidified in part before coming into contact with the post-Cambrian units. Most, if not all, of the contacts between the porphyry and the post-Cambrian rocks are accordingly believed to be fault surfaces." There is little evidence then, to indicate the time of crystallization of the syenite plug. The main body of syenite porphyry is very shattered in places and hydrothermal solutions have leached nearly all of the mafic minerals. Dikes of similar alkalic rocks intrude the syenite porphyry and these are generally quite fresh. The alteration and introduction of silica into the older syenite porphyry are thought to be the result of mineralizing solutions which produced the gold-silver deposits of the area (Knechtel, 1959, p. 745). Some of the sedimentary rocks show effects of these solutions also but there is little evidence of any contact metamorphism as a result of the syenite porphyry.

The situation is thus rather peculiar in this area. The time of emplacement of the syenite porphyry is early Tertiary, but the time of crystallization is difficult to determine. The contact between the syenite porphyry and the Precambrian was examined in one place. Somewhat rounded, partially assimilated xenoliths of mafic gneisses were recognized in the porphyry near the contact.



GENERALIZED GEOLOGIC MAP OF LITTLE ROCKY MOUNTAINS
AND ADJACENT PLAINS

0 5 MILES
SCALE

ALKALIC IGNEOUS ROCKS
(TERTIARY)

BEARPAW SHALE
(UPPER CRETACEOUS)

JUDITH RIVER FORMATION
(UPPER CRETACEOUS)

CLAGGETT SHALE, EAGLE SANDSTONE AND
COLORADO GROUP
(UPPER CRETACEOUS)

FAULT
● SAMPLE LOCATION

KOOTENAI AND ELLIS FORMATIONS
(LOWER CRETACEOUS AND JURASSIC)

MISSION CANYON LIMESTONE TO FLATHEAD SANDSTONE
(CARBONIFEROUS TO CAMBRIAN)

METAMORPHIC ROCKS
(PRECAMBRIAN)

Figure 10.--Geology of the Little Rocky Mountains (after Knechtel, 1959).

It was assumed that the xenoliths were blocks of Precambrian gneisses similar to those sampled. It is not known why the Tertiary syenite had no apparent effect on the K-Ar ages of either the biotite or hornblende.

AREA IX.

The Little Belt Mountains are somewhat similar to the Little Rocky Mountains except a larger area of Precambrian rocks is exposed. The general geology has been described in the Fort Benton and Little Belt Mountain Folios of the U. S. Geological Survey (Weed, 1899a and b). Pre-Beltian biotite and biotite-hornblende gneisses and schist are exposed; these are overlain by basal Neihart quartzite of the Belt series, which in turn is overlain by other Beltian and Phanerozoic rocks. During Tertiary time the area was the site of mountain building and associated volcanic activity. Numerous Tertiary igneous rocks, both intrusive and extrusive crop out in the area and many are alkalic in composition.

A geologic sketch map of the area showing the sample location is given (fig. 11). Biotite-hornblende gneiss was collected in a road cut about 7 miles north of Neihart. Biotite (AK 176) and hornblende (AK 265) were dated at 1.75 b.y. and 1.79 b.y. respectively (table 17). These dates agree with the possible analytical errors.

Hayden and Wehrenberg (1960) dated potassium feldspar from a granitic dike two miles north of Neihart at 1.33 b.y. This lower age is due to argon leakage. There is some evidence to indicate that the pre-Beltian rocks are much older than 1.7 b.y. and may have undergone two widely separated periods of metamorphism. Catanzaro and Kulp (1960) dated several zircons and monazites from these gneisses and interpret the results as indicating a



GEOLOGIC MAP OF PART OF THE LITTLE BELT MOUNTAINS

0 10 MILES
SCALE

— FAULT

● SAMPLE LOCATION

UNDIFFERENTIATED JURASSIC,
KOOTANAI FM., COLORADO SH.
(JURASSIC, CRETACEOUS)

MISSISSIPPIAN AND PENNSYLVANIAN
ROCKS UNDIFFERENTIATED

CAMBRIAN AND DEVONIAN
ROCKS UNDIFFERENTIATED

BELT SERIES
(MIDDLE AND UPPER PROTEROZOIC)

GNEISS, SCHIST AND RELATED ROCKS
(LOWER PROTEROZOIC OR ARCHEAN)

ALLUVIUM
(QUATERNARY)

TERTIARY SEDIMENTARY
ROCKS UNDIFFERENTIATED

FLOW AND PYROCLASTIC
ROCKS
(TERTIARY)

INTRUSIVE ROCKS
(TERTIARY)

Figure 11.--Geology of the Little Belt Mountains (generalized after Ross, Andrews, and Witkind, 1955).

1.9 b.y. event and suggesting a possible 2.4 b.y. event. No descriptions of the gneisses are given, but it is likely they may be of sedimentary origin in which case the dates may merely indicate the age of the source rocks from which the minerals were derived.

Gast (1961, p. 429) in a discussion mentions a Rb-Sr date of 2.4 b.y. on feldspar. No additional data is known about this date, but it is more convincing than the zircon and monazite dates in indicating that the rocks are actually older than shown by the K-Ar dates. It appears that the crystalline rocks may thus be related to those in the Beartooth uplift to the south. The 1.7 b.y. K-Ar dates are apparently the result of the Hudsonian orogeny.

AREA X.

South of the Little Belt Mountains pre-Beltian crystalline rocks are exposed in the Beartooth uplift. The Beartooth Mountains, and other Precambrian "block" uplifts occurring to the south and southeast, form the positive boundary features of the Big Horn basin of northern Wyoming. Similar Precambrian rocks also occur to the west in southwestern Montana. These features were uplifted during Laramide time, but the shapes are thought to have been controlled by Precambrian faults. This aspect is discussed in more detail in the section covering the basement of Montana.

No dates were determined from the Beartooth Mountains during the present study but considerable work has been done by other laboratories. A brief discussion of the general geology will be made and the dates available from this and adjacent areas are mentioned. Some of the dates are plotted on figure 20.

Recent articles by Eldersvaart and Bentley (1958), Spencer (1958), and Wise (1958) briefly review the area and mention something of the structural

features. The Beartooth uplift consists largely of a gneissic complex with varying amounts of migmatite from place to place. Metasediments are present throughout the range but occur mainly in the northern part. According to the descriptions of Poldervaart and Bentley (1958, p. 9) the metasediments have undergone a fairly high-grade of metamorphism. Of special interest is the Stillwater igneous complex occurring at the northern edge of the uplift. This complex basic body, which differentiated during crystallization, is thought to originally have been 25,000 feet thick. Hess (1960) has recently described the petrology of the intrusion in considerable detail.

Fold structures are recognized in the gneisses and these trend about north-south (See Spencer, 1958, p. 21). Fractures are a common feature throughout the uplift and Spencer (1958) has done a statistical study of the fractures based on both ground work and air photograph interpretation. Spencer states (1958, p. 21): "The pattern formed by the most prominent fractures is a striking one. It consists of two vertical sets at right angles (N. 45° W. and N. 40° E.), and two vertical sets which intersect at angles of 55 to 60 degrees and are bisected by the N. 45° W. set. This pattern would be expected if a plate of rocks were subjected to compressive forces acting along a NW-SE line." Bordering faults of similar attitudes are known to outline the Beartooth uplift and similarly orientated faults occur in the basement to the north (fig. 13). Dikes occupy most of the known fracture directions and one such dike has been dated at 2.5 b.y. which according to Spencer (1958, p. 21) gives a minimum age of fracturing in the area.

Gast, et al (1958) did the original reliable dating in this area. Seven Rb-Sr dates on biotite, microcline, and muscovite range from 2.38 to 2.63 b.y. Four K-Ar dates on biotite and muscovite range from 2.29 to 2.52 b.y. Biotite from the northern Bighorn Mountains has given a Rb-Sr

date of 2.59 and a K-Ar date of 2.54 b.y. Hayden and Wehrenberg (1960) dated hornblende from an amphibolite exposed at Quad Creek in the Beartooth Mountains at 2.45 b.y. by the K-Ar method. An Archean age for the Beartooth uplift is confirmed. Recent Rb-Sr dating by Giletti and Gast (1961) indicates the extent of the Archean terrane in Wyoming.

The Precambrian rocks of southwestern Montana appear to be considerably younger than those in the Beartooth uplift. Giletti and Gast (1961, p. 445) have presented 10 Rb-Sr dates from this area ranging from 1.46 to 1.70 b.y. Hayden and Wehrenberg (1960, p. 95) have dated biotite by the K-Ar method at 1.63 b.y. Giletti and Gast (1961, p. 457) interpret their dates as indicating a rock forming event at about 1.60 b.y. which would reduce to 1.50 b.y. using the new decay constants. This event, if real, is somewhat later than the main period of the Hudsonian orogeny as indicated by the present study and the results of other workers. Dates obtained on samples from the Grand Tetons in Wyoming are not in agreement. Three Rb-Sr dates are 2.50, 1.87 and 1.28 b.y., suggesting to Giletti and Gast (1961, p. 455) that the area may be a boundary zone between geologic provinces of different ages.

Thus radioactive dating has indicated the presence of a third Archean nucleus in North America. In Montana and Wyoming the uplifts represented by the Beartooth, Bighorn, Casper, Owl Creek, Wind River, and in part the Grand Teton Mountains appear to be part of this ancient Precambrian terrane. Younger Precambrian rocks are exposed to the northwest, north, east and south.

Major Features of the Precambrian Basement Surface

The following section gives a summary of the known and inferred features of the Precambrian basement of Alberta, Saskatchewan, Manitoba, Montana, North Dakota, and South Dakota. This discussion refers to the basement surface as it is now, and no attempt is made to reconstruct or to describe the various and complex fluctuations of this surface throughout Phanerozoic time. Two papers of regional scope discuss this aspect (Webb, 1954; Pye, 1958) and the reader is referred to these for discussions on Phanerozoic sedimentation. Of special interest to the present investigation are the basement features which may have been controlled by a tectonic framework developed in Precambrian time, and the possible relation or correlation of this framework with structural features of the exposed shield areas.

Rejuvenation of older Precambrian faults may be the cause of many structures in the cover rocks. In the Cordilleran foreland region of Montana, basement control has been demonstrated by the presence of Precambrian faults, but in other areas, such as parts of Saskatchewan and Manitoba salt-solution tectonics may have been the controlling factor in the development of many Phanerozoic structures. Though it is difficult to resolve structures caused by salt solution or by other mechanisms, basement control may be suspected where fault patterns suggest regional stress conditions rather than vertical subsidence.

In this discussion a brief interpretation of available geophysical data is made. Sawatzky and Agarwal (1958) have compiled the available aeromagnetic data for Saskatchewan. An area in west-central Saskatchewan has been surveyed aeromagnetically by the Geological Survey of Canada (1957) and a compilation is presented (fig. 14). Aeromagnetic maps are

also available for an adjoining area to the west in Alberta. These have been compiled and interpreted by Garland and Bower (1959) and in part by Agarwal (1960). Regional gravity anomaly maps have been prepared for Saskatchewan by Sawatzky (1959). Gravity maps of Manitoba, Saskatchewan, and Alberta (Miller and Innes, 1952), and of Canada (Innes, 1960b) have been published by the Dominion Observatories.

Reports which are interpretative in nature and pertinent to the present discussion are those of Garland and Burwash (1959), Garland and Bower (1959), Agarwal (1960), and Wilson and Brisbin (1961).

Lines representing axial traces of linear gravity and magnetic anomalies are shown on figure 13. No attempt has been made to indicate the relative magnitudes of these features but they are all rather evident on the maps from which they were taken. The linear anomalies may represent belts or bands of different rock types within the basement as indicated by the interpretative studies mentioned above. Thus, the regional pattern formed by the anomalies may be an indication of the geologic fabric of the basement.

A structure contour map of the Precambrian basement surface was compiled from various sources (fig. 12). The Alberta, Saskatchewan and Manitoba portion of the map was completed by R. A. Burwash with only slight modifications by the writer in southwestern Saskatchewan. The Montana data were supplied by D. L. Blackstone and the South Dakota contours are after Steece (1961). The writer contoured available well data from North Dakota.

MONTANA

Regional Setting.--The regional geology and tectonics of this and adjacent areas can best be seen by referring to the Geologic Map of Montana (Ross, Andrews, and Witkind, 1955), the Geologic Map of the United States (Stose, 1960), the Tectonic Map of the United States (Am. Assoc. Petroleum Geologists, and U. S. Geol. Survey, 1961), and the tectonic map of the central Cordilleran foreland (Osterwald and Dean, 1961). Various papers appearing in the Billings Geological Society Guidebooks are also useful for their recent accounts of geology and structure of various parts of Montana. A tectonic sketch map of North America prepared by Thom (1959) is useful although certainly interpretative.

The major tectonic provinces of Montana are shown by Eardley (1951, p. 285) and Osterwald and Dean (1961, p. 339). The Montana Rockies extend south from the Canadian Rockies to approximately 47 degrees latitude north where they are terminated by the Idaho batholith and other intrusions and structural features. Mountains with similar structural features form the Central Rockies of which the Wasatch Range of Utah, Idaho, and western Wyoming are a part. The Montana and Central Rockies form part of a much larger feature--the Cordilleran geanticline (Osterwald and Dean, 1961, p. 339). The Cordilleran foreland occurs east of this feature and is in turn bounded on the east by the Interior platform (Osterwald and Dean, 1961, p. 339). In Montana the Cordilleran foreland includes the Central Montana Rockies. Lying north of the Central Montana Rockies is the Northern Great Plains tectonic province of Thom (1957) or the Central Stable Platform of Alpha (1955), both of which are part of the Cordilleran foreland. Osterwald (1956, p. 329) describes the predominant geologic structures

within the foreland as . . . "a series of anticlinal mountains and broad asymmetric valleys that contrast sharply with the folds and overthrusts related to the Cordilleran geanticline to the west".

With specific reference to Montana and adjacent areas, Chamberlin (1945) describes the relations in more detail and says that the Canadian and Montana Rockies and similar structures in the Central Rockies to the south in Utah, Idaho, and western Wyoming exemplify geosynclinal deformation of the Appalachian type, whereas the Central Montana Rockies represent foreland deformation and resulting structures. In the two areas of geosynclinal deformation the Paleozoic and Mesozoic sedimentary rocks formed a thick sequence and the underlying basement was at considerable depth. Laramide deformation in both of these areas produced long linear folds and regional overthrust faults (Chamberlin, 1945, p. 99-101). In the platform area of Montana and Wyoming, part of the Cordilleran foreland, Paleozoic and Mesozoic sedimentation did not produce such thick deposits and because the basement was much nearer the surface it exerted more control over the type of deformation that occurred in Laramide time. Chamberlin (1945, p. 102) says that . . . "in place of long parallel folds of the Appalachian type, there resulted chiefly an uplifting of block-shaped or oblong ranges and a sinking of intermontane basins. Crustal shortening was only moderate". Eardley (1951, p. 287) summarizes the geology in a similar way: "The Central Montana Rockies are due mostly to vertically acting forces, including intrusive activity of magmas, and in this way differ from the Rockies which are chiefly of compressive origin". Thom, in his discussion of the wedge-uplifts of the Central Montana Rockies points out the importance of compressive forces in the formation of these features: "All four of the wedge-uplifts features referred to (Northern Bighorn, Owl Creek, Beartooth, and Phillipsberg uplifts) owe

their immediate origin to the application of tangential compressive forces to rock bodies having such form or arrangement (downward pointing wedges) that the release of the compression was most easily accomplished by upward movement". (1955, p. 371-372).

A feature of importance transecting the Cordilleran foreland of Montana and Idaho is formed by a rather wide belt of Tertiary intrusions extending in a northeasterly direction from southeastern Idaho to the Bearpaw and Little Rocky Mountains in Montana. (See Eardley, 1951, p. 285 and 343). This feature has been referred to as the Idaho porphyry belt (Ross, 1933, p. 270). A plot of earthquake epicenters in Montana revealed a concentration more or less along this porphyry belt indicating its recent tectonic instability (Woolard, 1958, p. 1136).

Basement Features.--The portion of the Cordilleran foreland formed by the Central Montana Rockies and the plains area lying to the north is the main area of interest with regard to the present discussion of the Precambrian basement of the western Canada sedimentary basin. Some of the main features recognized in the basement surface are shown on figures 12 and 13. The present configuration of the Precambrian basement of this area can be related to a great extent to Laramide deformation. The larger uplifts and basins were controlled by early segmentation by faulting of the Precambrian crystalline rocks. Many of the smaller domal uplifts are related to Tertiary intrusions, the location of some of which may also have been controlled by Precambrian structures. Alpha (1955, 1958); Alpha and Fanshaw (1954); Bucher, Thom, and Chamberlin (1934); Chamberlin (1945); Cooper (1956); Foose (1958); Osterwald (1956); Osterwald and Dean (1961); Pye (1958); Sonnenberg (1956); Thom (1955, 1957); and Wise (1958) have all

discussed basement features and basement control on younger features. The report of Osterwald and Dean (1961) is extremely useful in obtaining a regional picture of the tectonics of the area.

As mentioned in the discussion of regional setting, the basement rocks entered into the Laramide deformation of this area to a greater extent than in the Cordilleran geanticline. The actual pattern of deformation has been related to previously existing structures in the Precambrian rocks. Thom (1957) discusses the development of this Precambrian framework of Montana and parts of Wyoming and relates this framework to the later Laramide deformation. Thom's development begins with the northeasterly trending geosyncline in Wyoming and Montana which he calls the Cherry Creek orogenic system. Subsequent to the deposition of sedimentary rocks in this geosyncline, compressive forces produced folding with axes trending about N. 60° E. and a tensional fault system oriented N. 30° W. along which Precambrian granites were emplaced. Shear fractures developed with orientations of N. 15° E. and N. 75° W. With regard to the segmentation of the crust by these features Thom (1955, p. 373) says that . . . "individual basement rifts belonging to the three major fracture systems had linear extents measurable in hundreds of miles and divided the outer crust into regional mosaic blocks which have controlled and given character to tectonic happenings within the area since early Precambrian time". This idea is in agreement with the statement of Osterwald and Dean (1961, p. 341) that the . . . "predominant trends of most tectonic structures in the Cordilleran foreland are northwest, northeast, and west to west-northwest; these trends probably originated during Precambrian time . . . and although many individual structures are probably much more recent in age, they may be genetically related to structures of Precambrian age . . ."

The three most evident faults recognized in the cover rocks of the Central Montana Rockies which are thought to have their origin in Precambrian faults are the Nye-Bowler, Lake Basin, and Cat Creek fault zones (fig. 13). These three parallel fault zones are oriented somewhat north of west and are Thom's (1957) N. 75° W. shear direction of the Cherry Creek orogenic system. The surface expression of these shear zones are a series of en echelon faults of tensional nature striking northeast. Left-hand displacement for the basement rifts has been suggested to explain the en echelon faults. The Nye-Bowler lineament has associated with it volcanic features and laccoliths (Alpha and Fanshaw, 1954, p. 77). The Lake Basin or Huntley fault zone as it is sometimes referred to, may be part of a very large fracture of continental nature--the Osborn fault zone or the Coeur d'Alene lineament (Alpha and Fanshaw, 1954, p. 78; Wisser, 1959; Moody and Hill, 1956). The Nye-Bowler fault, which may continue eastward to the Black Hills uplift (Osterwald, 1956, p. 330), forms the approximate limit of the Beartooth uplift and the block lying to the north is depressed and forms the basement of the Crazy Mountain syncline. North of the Cat Creek fault zone another downthrown block forms the rather poorly defined Blood Creek syncline and between the Cat Creek fault and Lake Basin fault a number of structural features are present. (See Sonnenberg, 1956, p. 78-80). The western end of this segment is partly occupied by the Little Belt and Big Snowy uplifts, and the Porcupine dome is a basement "high" at the eastern end.

The Little Belt uplift is of special interest because crystalline Precambrian rocks, overlain by the less metamorphosed Beltian series, crop out near the center of the uplift (fig. 11). The buried northwesterly extension of the Little Belt uplift has been called the South arch and it is thought to be continuous with the Sweetgrass arch to the north although two basement

faults, the Pendroy and Scapegoat-Bannatyne (Genou trend), intervene between these structural highs (Alpha, 1955, p. 129).

The Scapegoat-Bannatyne and Pendroy faults parallel the direction of the Idaho porphyry belt and may be complimentary shear directions of the Nye-Bowler, Lake Basin, and Cat Creek rifts. (See Thom, 1957). Sonnenberg (1956, p. 78) states that similar trending faults of importance occur in central Montana and the intersections of these with the more westerly trending faults may have provided zones of weakness for the alkalic Tertiary intrusions present in the area. Two regional faults with similar strikes, the Weldon and Brocton-Froid faults, occur in northeastern Montana and are probably Precambrian in origin (Osterwald and Dean, 1961, p. 346).

The Sweetgrass arch mentioned above is partly formed by the Kevin-Sunburst dome resulting from Tertiary intrusions. The northerly extension of the Sweetgrass arch in Alberta is represented in the basement by a long, north-trending nose. East of the Sweetgrass arch, the Bearpaw Mountains are associated with Tertiary intrusions and volcanic rocks (Reeves, 1953) and the Little Rocky Mountains form a positive area to the southeast (fig. 13). Both of these features are reflected in the basement as domal uplifts. The Bearpaw uplift has associated with it many thrust faults, but these are restricted to the younger sedimentary rocks.

Further east, the Bowdoin dome forms a positive feature (Schroth, 1953) that extends northward into Saskatchewan where the continuation has been referred to as the Val Marie arch (Kamen-Kaye, 1953). East of the Bowdoin dome the basement surface has an eastward slope towards the center of the Williston basin in North Dakota.

The main basement features in eastern and southeastern Montana are the Cedar Creek or Baker-Glendive anticline (Gilles, 1952) and the northwestern extension of the Black Hills uplift (Noble, 1952). The Cedar Creek

anticline is a remarkably straight feature striking northwest and is probably related to a basement fault (Osterwald and Dean, 1961; Kornfeld, 1954). The surface expression is well shown by a long linear belt of Upper Cretaceous rocks surrounded by the Paleocene Fort Union formation. (See Ross, Andrews and Witkind, 1955). The Black Hills uplift parallels the Cedar Creek trend and the basement expression is a rather broad north-westward plunging nose, with smaller crenulations superimposed on it (Osterwald and Dean, 1961; Noble, 1952). West of this high is the Powder River basin which is bounded in turn on the west by the uplifted block of Precambrian rocks of the Big Horn Mountains.

In summary, the basement of Montana as referred to here has a surface which is characterized by domal and polygonal shaped uplifts and linear features produced by faults. The control over the locations of these features is a tectonic or structural framework developed in the Precambrian and re-activated during Laramide mountain building. Tertiary intrusions have been largely responsible for many of the domal uplifts and the position of many of these may also be related to Precambrian zones of weakness. In addition to the control over Laramide structures the older Precambrian framework is thought to have had control also over Beltian, Paleozoic, and Mesozoic sedimentation.

NORTH AND SOUTH DAKOTA

Regional Setting.--Physiographically North and South Dakotas belong to the Interior Plains region which is divided into the Great Plains province on the west and the Central Lowland province on the east (Lobeck, 1948). Tectonically a similar two-fold division has been proposed. The western parts of the two states belong to the Cordilleran foreland, and the eastern

parts to the Interior platform (Osterwald and Dean, 1961, p. 338-339).

This division is defined mainly on the basis of geophysical data and it separates northwest trending gravity and magnetic anomalies in the foreland from northeast trends in the platform area (Osterwald and Dean, 1961, p. 338).

No Precambrian rocks are exposed in North Dakota but shield is exposed just to the east in Minnesota. In South Dakota limited granite exposures occur at the upper end of the Minnesota River valley, and to the south near the junction of the boundaries of South Dakota, Minnesota, and Iowa a much larger area is underlain by Sioux quartzite of Precambrian age. The third area of exposed Precambrian rocks in South Dakota is in the Black Hills.

The major features of this area which are recognizable in the basement surface are the Williston Basin, centered in North Dakota, the Black Hills uplift, and the Sioux uplift. Many more structural features are evident in the cover rocks and the regularity of orientation of many of these suggests that they have resulted from re-activation of older structures, perhaps in the Precambrian basement (Osterwald and Dean, 1961, p. 343).

Basement Features.--The Williston basin is the most prominent feature of this area. Figure 13 shows the approximate position of the -6000 foot basement contour which more or less outlines the central part of the basin. The depth from the present day surface to the basement in the center of the basin is in excess of 15,000 feet. Paleozoic and Mesozoic rocks are present in the Williston basin; the average Mesozoic section is 6000 feet thick, and 5000 to 7000 feet of Paleozoic rocks, mostly carbonates, are present (Barnes, 1953, p. 340).

The areal limits of the Williston basin have been defined differently by different authors. Osterwald and Dean (1961) give the southwest limit as the Cedar Creek anticline and the northeast limit as the Missouri Coteau.

Most other writers consider a much wider extent to the basin and some have extended it north and east to the Canadian shield and northwest and west to the Battle Creek saddle and Sweetgrass arch, but other intermediate limits are also used (Barnes, 1953; Bishop, 1954; Porter and Fuller, 1958; Kornfeld, 1954, Link, 1958). Regardless of the outer limits, the deepest and central part is in western North Dakota.

The most obvious basement structure within the main part of the Williston basin is the northerly trending Nesson anticline (fig. 13). Many more structures occur in the exposed rocks; some may be related to older, perhaps Precambrian, structures and at least some of the domal structures are thought, on the basis of geophysical data, to be related to igneous intrusions (Osterwald and Dean, 1961). From the center of the basin eastward the basement surface is a rather featureless, slightly curved plane with a rather uniform gradient upward towards the exposed shield.

Kornfeld (1954) in his discussion of seismic problems in the Williston basin made some interesting speculations concerning the nature of the basement rocks. He presents a basement geologic map, based on geophysical data, showing a belt of metasedimentary rocks extending north from the Black Hills along the Cedar Creek anticline to the Canadian border. This belt is bounded on either side by schists of the Lead series. On the eastern flank of the basin he shows a contact separating the Lead series from predominantly granitic shield rocks. This contact also represents a change from easterly structural trends in the east, to northwesterly trends in the west. This suggested change in structural trends may be the same feature Osterwald and Dean (1961, p. 338) refer to as supporting evidence for the tectonic division of the area. The main point of interest is that the contact which Kornfeld presents corresponds very closely to the probable boundary between the Churchill and Superior provinces of this area (fig. 20).

The basement surface in South Dakota is more complex than in North Dakota. (See Steece, 1961). The southern extension of the Williston basin, the Lemmon syncline, is bounded on the southwest by the Black Hills uplift where the Precambrian rocks are exposed at elevations greater than 7000 feet in places. About 250 miles to the north the Precambrian surface is more than 14000 feet below sea level. Osterwald and Dean (1961, p. 345) consider the Black Hills uplift to be part of a large-scale structural arch that extends from Kansas as the Central Kansas uplift, through Nebraska as the Chadron arch, northward through the Black Hills and possibly connects with the Porcupine dome in Montana. The limiting feature of the Lemmon syncline to the southeast is the Central Dakota terrace (Osterwald and Dean, 1961, p. 344). The Precambrian surface representation of this feature is shown by the basement contours (Steece, 1961).

In summary, the main feature of the North and South Dakota basement surface is the deep and extensive Williston basin. Over most of these two states the gradient of the basement surface is directed towards the center of the basin in western North Dakota. Bounding features of this area include the Precambrian shield to the east, the Sioux uplift to the southeast, and the Black Hills uplift to the southwest. Geophysical evidence indicates changes in the Precambrian structural trends that may represent the Churchill-Superior boundary.

MANITOBA

Regional Setting.--The sedimentary area of southern Manitoba is bounded on the north and east by the Precambrian shield. A large part of this contact is covered by Lake Winnipeg, and for most of the remaining length no actual contact is exposed between the shield rocks and the overlying

Ordovician sedimentary rocks. From the boundary of the exposed shield the basement surface shows a steepening gradient to the southwest towards the center of the Williston basin. Only the regional nature of the Precambrian surface is known and the basement contours show a rather featureless surface (fig. 12). However, as Baillie (1952, p. 10) points out, the surface is uneven, and good evidence for this occurs in the Lake St. Martin area where Precambrian rocks protrude through Ordovician and Silurian formations.

Basement Features.--The most obvious basement features which has had control on later sedimentation, if not on structure, is the aforementioned Precambrian inlier in the Lake St. Martin area. Just west of this inlier evaporite deposits of gypsum occur and Baillie (1951, p. 35) says that these Precambrian granite hills . . . "were probably islands in many of the post-Precambrian seas, and locally, restricted basinal conditions with associated evaporite deposition could have occurred in this area during temporary withdrawal of the seas during Paleozoic and Mesozoic time."

Faulting is evident in places in the Paleozoic and Mesozoic sedimentary rocks, and the possibility of basement control cannot be completely excluded in favor of salt-solution tectonics as possible causes for such faulting. Edie (1958, p. 117) mentions probable faulting in the Hartney area of Manitoba where a well revealed a missing section of Mississippian rocks. Meek (1958, p. 19) in reference to this area says: "Faulting known in the Hartney area of Manitoba may be a reflection of basement instability. The schist underlying the Hartney fault block is thought to be an erosional remnant of a schistose terrain that was protected by down-faulting; the movement evident in higher horizons was a result of recurrent movement along this old fault plane." In the Virden-Roselea and North Virden fields (McCabe, 1959, fig. 27), Milne and Nickoloff (1955, p. B-81) described faults

with strikes of N. 10° to 30° W. They favor salt solution as the causative factor.

McCabe (1959, p. 51) says, with regard to structures in the upper and lower Lodgepole units of Manitoba, that basement tectonics may have been important, but for some of the structures such as the Mandak basin (ibid. fig. 9) salt solution is a more likely cause.

In summary it may be said that basement structures and their possible control or effects on later sedimentation and structural features are poorly known in Manitoba. The Lake St. Martin inlier shows the best example of the effect of Precambrian surface topographic features on later sedimentation, and undoubtedly similar relief existed elsewhere on this erosion surface. Much of the faulting in the overlying sedimentary rocks is attributed to salt solution tectonics, however, basement control has been suggested as the governing factor for some structures.

SASKATCHEWAN

Regional Setting.--The Precambrian basement surface of Saskatchewan on a regional scale forms a rather featureless, southwesterly-dipping plane from the exposed shield on the north to south-central Saskatchewan (fig. 12). Along the International Boundary the shape of the basement greatly reflects the Williston basin, centered in North Dakota. In southwestern Saskatchewan several buried ridges and troughs are present on the Precambrian surface. Basement well control is such that several interpretations can be made as to the shape of these features.

In general, the Precambrian surface of Saskatchewan is not as complex in character as that of Montana and North Dakota. This may be apparent in part, because of lack of sufficient basement control. Many of the basement

features in the Dakotas and especially Montana are well shown in structures in the overlying rocks and can thus be recognized, whereas in Saskatchewan, such indicative structures are few in number. Haites (1960) in a recent paper on transcurrent faults in western Canada shows only four high angle faults in the sedimentary area of Saskatchewan and none have been proven to be basement controlled. In southwestern Saskatchewan some basement controlled structures are evident, and it is significant that the area is adjacent to the more disturbed area to the south in Montana.

Basement Features.--Some of the basement features of a more regional nature are shown on figure 13. In north-central Saskatchewan the North Battleford arch forms a rather broad, southwesterly-plunging nose and appears to mark the change in regional attitude of the basement surface in this area. To the west in Alberta the basement slope is more towards the west-southwest. The North Battleford arch apparently corresponds with the lineament shown by Sikabonyi (1957, p. 24) connecting with the Sweetgrass arch to the southwest. The broad, low feature lying between the Sweetgrass arch and the North Battleford arch has been called the Battle Creek saddle and is interpreted by Bishop (1954, p. 481) as part of the separating feature between the Williston basin to the southeast and the Alberta basin on the west.

Adjacent to the shield in the vicinity of Lac la Ronge the Tectonic Map of Canada (Derry, 1950) shows two faults striking southwest from the regional trends in the shield and cites geophysical evidence suggesting post-Cretaceous movement on these Precambrian faults. To the west in the vicinity of Lac Ile-à-la-Crosse, Aragwal (1960) shows two similar trending faults in the basement on the basis of aeromagnetic interpretations. A lineament of more regional magnitude has been described to the south by Van Hees (1958). This is the Meadow Lake escarpment which represents a subsurface erosional

lineament that originated in pre-Devonian time. The lineament has an arcuate shape extending from near Deschambault Lake, Saskatchewan, some distance towards the southwest into Alberta. According to Van Hees (1958, p. 70) Silurian, Ordovician and 1000 ft of Cambrian rocks were eroded from the area north of the escarpment. On the present basement surface there is no indication of the escarpment, but the alignment with the Kisseynew lineament occurring the the shield area to the east has led to the idea that basement faulting was the possible cause of the Meadow Lake feature. One of the hypotheses entertained by Van Hees (1958, p. 76) to explain the lineament is that of repeated but opposite movement along a basement fault. This idea is described in detail (op. cit. p. 76) but essentially it consists of an uplift of the north block, subsequent erosion of part of the lower Paleozoic section, and eventually reversal of movement along the fault to replace the basement surfaces of the two blocks into juxtaposition. Haites (1960, p. 45) thinks that the relations could be explained equally well by transcurrent movement of some magnitude along the Precambrian fault plane and that a reversal of movement is not required.

A northwesterly striking fault in the vicinity of Yorkton has been shown to have right-hand transcurrent displacement on the order of one to two miles (Sawatzky, 1959). The evidence is in the form of displacements of seismic contours on top of the Paleozoic erosion surface and it seems likely that a fault of such magnitude had effect on, or originated in the basement.

A number of possible faults occur in southern Saskatchewan. Some of these appear related or attributable to salt tectonics, involving the removal of Devonian Elk Point evaporites from a large area in southwestern Saskatchewan. Kupsch (1958, p. 125, fig. 11) shows the area in which no salt occurs and points out that the northern limits can be represented well by straight lines.

He notes further that the limits of evaporites closely parallel two major topographic features of the area, namely the escarpments of the Missouri Coteau and the Cypress Hills. The northwesterly trending limit of evaporites also parallels the escarpment formed by Mississippian limestone as shown by seismic maps (Sawatzky, 1959). Kupsch (1958, p. 125) reasons that this escarpment may have been caused by a fault which in later time was reactivated to produce the Missouri Coteau escarpment. He thinks a similar origin may have produced the Cypress Hills escarpment. With regard to the distribution of evaporites, Kupsch (1958, p. 125) states: "Rather than regarding salt solution as the cause of faulting the writer suggests tectonic faulting as responsible for the salt deposition."

With regard to more specific areas, several faults are thought to exist in the Regina area. The Avonlea fault strikes northwest and the Truax fault, for which 2 1/2 miles of left-hand transcurrent movement is postulated, strikes about north ~~erly~~ (Haites, 1959, p. 170). In the same area Kupsch and Wild (1958, p. 131) show two dominant directions of lineaments determined from air photographs: northeast, and northwest parallel to the Missouri Coteau. Haites (1959, p. 167-175) summarizes the previous ideas concerning the origin of the faults in this area. Edie (1956) and Kupsch and Wild (1958) suggest recurrent movement along Precambrian fault planes. Kupsch and Wild (1958, p. 133) further state: "The pattern of the lineaments in the Avonlea area is different from that expected if local salt collapse were the cause of faulting. The distinctive conjugate pattern appears to be the result of stresses affecting the rocks over a wide area. Salt solution would tend to produce a rather irregular, localized pattern with a radial tendency over solution caves."

Opposing views have been presented by Sawatzky, Agarwal and Wilson (1959, p. 82) and others. They interpret seismic and drill hole data to

indicate that the faults described in the Avonlea area are non-existent and the structures evident were caused by removal of Devonian salt. To explain these structures the authors invoke continuous but preferential loci of salt removal.

A fact very strongly suggesting basement faulting is the record of an earthquake in 1909 which had its epicenter near Regina. Both Kupsch and Wild (1958, p. 134) and Haites (1959, p. 173) think that an earthquake of such magnitude could only have occurred as result of a deep-seated tectonic event such as faulting, rather than a collapse phenomenon resulting from salt solution. The Regina earthquake epicenter is reported to be on line with those occurring along the porphyry belt in Montana. (See Woollard, 1958, p. 1136).

According to Meek (1958, p. 17) probable basement faulting occurs in the Elbow area of Saskatchewan. The Elbow structure and a similar domal feature occurring about 3 miles to the south, the Gilroy structure, are described by deMille (1960, p. 154-162). The Elbow structure is indicated by a dome in Mesozoic rocks which are underlain by a disrupted mass of Paleozoic rocks. It is shown by a positive gravity anomaly, and seismic data outlines the structure rather well. A seismic reflection map on Silurian strata is interpreted by deMille (1960, p. 158) as suggesting faults bounding both the Elbow and Gilroy structures. Both structures are thought to be cryptovolcanos (deMille, 1960). With specific regard to the Elbow structure, deMille (1960, p. 162) concludes that . . . "It experienced explosive activity about the close of Paleozoic time when many American cryptovolcanos were active. Superheated steam rising from a great depth probably supplied the disrupting force. In Late Cretaceous or Tertiary time it was modified by the elevation of the Paleozoic core to form a

circular structure in the Mesozoic strata." The cryptovolcanic theory is favored by deMille over salt solution and salt piercement.

In the southwest corner of Saskatchewan several basement topographic elements are present. At least some of the basement relief now present was thought to have been present in Cambrian time. Structures in overlying Deadwood sandstones are the result of differential compaction over these ancient paleotopographic highs (Fyson, 1961, p. 16). The Bowdoin dome lying mostly in Montana is shown by the basement contours of Saskatchewan where it is called the Val Marie arch (Kamen-Kaye, 1953, p. 119). North of this high, a southeasterly plunging nose occurs which has been named the Swift Current anticline (op. cit., p. 121). Separating these two features is a trough recognizable on the basement surface. This apparently corresponds to the Ponteix syncline observed in the overlying sedimentary rocks (Kamen-Kaye, 1953, p. 121). A complete review of the structural anomalies and inferences with regard to age and origin of this area is presented by Sawatzky, Agarwal, and Wilson (1960, p. 20-26) in conjunction with their discussion of helium occurrences.

In a study of surface fracture patterns on a regional scale, Mollard (1958, p. 113) notes that in southern Saskatchewan and Manitoba the dominant lineaments strike northwest and northeast. These trends are thought to correspond to fracture patterns in the Precambrian.

Geophysical Data.--Some of the gravity and magnetic anomalies occurring in southern Saskatchewan are shown qualitatively on figure 13. Of major interest is the regional gravity low, which is an extension of the Nelson River low previously mentioned. Wilson and Brisbin (1961) have done the most work on this feature and consider this extension as representing the division of the Churchill and Superior provinces. A further extension

can be recognized in North Dakota from the gravity map of the United States (Jacobs, Russell, and Wilson, 1959, p. 99). Associated with the gravity low and essentially parallel to it are gravity highs.

Other gravity anomalies taken from sources previously mentioned are also shown in figure 13. The majority of the anomaly trends in southern Saskatchewan strike essentially northerly although deviations occur. It is likely that these anomalies result from the regional fabric and large-scale compositional banding of the basement rocks. South of Moose Jaw both gravity highs and lows show a concentric arcuate pattern that appears to correspond to the limits of Devonian evaporites as shown by Kupsch (1958, p. 125). Just to the north of these anomalies, a broad magnetic low occurs over the escarpment of the Missouri Coteau. This may reflect features in the basement or variations in the magnetic properties of the Phanerozoic rocks. In the southwest corner of Saskatchewan several northeasterly magnetic trends occur (Sawatzky and Agarwal, 1958). These are not well defined linear anomalies and the trend lines show are rather interpretative. This area is known to have considerable relief on the basement but the trends of the ridges and troughs appear to strike northwest (figs. 12 and 13). It is interesting to note that the trend directions of the magnetic anomalies, although somewhat interpretative, parallel approximately the direction of the Cypress Coteau and known faults in Montana. It may well be that basement topography of this area is caused in part by faulting.

Forty-eight aeromagnetic maps are available for an area in west-central Saskatchewan. These have been compiled and reduced with the results shown on figure 14. The area is bounded by latitudes 54 and 56 degrees and longitudes 107 and 110 degrees. The northeast corner of the area includes part of the exposed shield. The most obvious magnetic anomaly in the area is a complex linear positive feature trending north-northeast in the eastern



AEROMAGNETIC MAP

MAGNETIC ANOMALIES



Figure 14.--Aeromagnetic map of west-central Saskatchewan.

one-third of the area. A positive anomaly with similar orientation occurs in the northwest corner of the area. In the north-central part the magnetic anomalies are suggestive of a somewhat circular structure. The southwestern corner of the area is rather featureless. The overall magnetic picture is complicated by the non-uniform depth to basement. In the northeast corner the shield outcrops and the anomalies are sharp and well defined, whereas in the southwest corner the basement is at a depth of 3000 feet or more, and the anomalies are more broad and not as well defined.

Agarwal (1960) has also compiled the aeromagnetic maps from this and the adjacent area to the west of Alberta. From the magnetic patterns Agarwal (1960) constructed a basement lithology map. As far as the present writer is concerned the important features of figure 14 are the orientations and character of the magnetic anomalies. The elongate trends are thought to reflect the compositional and structural fabric of the basement. These trends are consistent with those known in the adjacent shield area. Well control is poor in the area and only four basement cores are available (fig. 12). The samples include one granite, two quartz monzonites, and one biotite-quartz-feldspar-gneiss. The writer is in agreement with Agarwal (1960) in his interpretation of the southwest corner of the area as being underlain by granitic rocks. Agarwal divides most of the remaining area into mafic and granitic gneisses, the magnetic highs being underlain by the mafic rocks. In the Lac la Ronge area the magnetic contours are parallel to the regional structural trends, but a band of mafic gneisses is associated with a magnetic low (P. Money, personal communication). Therefore, rather than assuming specific rock types as the cause of the anomalies, it seems safer to conclude that the regional magnetic anomaly pattern is controlled by variations in rock type, the exact nature of which is not known. The

linear anomalies are assumed to be controlled by the basement fabric both structurally and compositionally.

Summary.--The basement surface of north central Saskatchewan is a rather featureless plane sloping towards the southwest. Faults with Paleozoic or later movements may be present, but they have not been proven because of insufficient basement control, reversal of movement, or lack of vertical movement. The main features of regional magnitude in southern Saskatchewan are the northern part of the Williston basin and the highs and lows in the southwestern corner of the province. Basement-controlled faulting has been suggested to explain some of the structural features in the overlying rocks, but salt-solution is emphasized by some writers as the controlling factor. Orogenic instability of the region is supported by the record of the Regina earthquake. The proximity of southern Saskatchewan to the more disturbed areas to the south in Montana and South Dakota support the view that basement control has been important in the formation of at least some of the structures evident in the younger rocks.

Geophysical data indicates the regional fabric of the basement. Near the shield in west-central Saskatchewan continuations of the known northeast trending structures are suggested by magnetic data. Further south the gravity and magnetic anomalies suggest structural trends which appear to more or less parallel the boundary between the Churchill and Superior provinces. Local deviations may be due to basement relief or faults.

ALBERTA

Regional Setting.--The geological boundary features of the basement area discussed here, are the eastern limit of the front ranges of the Rocky Mountains on the west and the Precambrian shield in the northeastern corner of Alberta.

Regionally there exists in Alberta situations somewhat similar to those in Montana and Wyoming with regard to the Rocky Mountains. The Rockies adjacent to this area on the west are similar in structural style to those in northern Montana. Thrust faults and folds of the Appalachian type are distinguishing structural characteristics. To the north of the present area of discussion the Mackenzie Mountains are of different tectonic style and are similar to the Central Montana Rockies. Although the geologic relations of the Mackenzie Mountains are not nearly as well known as their analogs to the south, the general similarities are evident (Goodman, 1954, p. 347-350). Goodman (ibid.) points out that basement control over later developed structures has been of prime importance. In general the structures are large, broad folds, and features characteristic of the Canadian Rockies to the south are essentially absent. It is noteworthy that in Montana-Wyoming area where the tectonic style of the Rocky Mountains changes from overthrusts and long parallel folds to block faulting with much basement control there exists an older nucleus in the basement rocks, i.e. the Big Horn-Beartooth and associated uplifts. Similarly, in the southwestern District of Mackenzie where the style of mountain-building changes, the Yellowknife nucleus of Archean age lies to the east.

The Alberta shelf comprises a major part of the western Canada sedimentary basin. The western limit discussed above is a structural feature and the crystalline Precambrian basement may extend some distance further westward, but it is not known how far. This situation is complicated by the fact that during Middle and Upper Proterozoic time great thicknesses of sedimentary rocks were deposited in this western marginal area which may have been floored by older continental crustal rocks or in part by oceanic crustal rocks.

The basement surface of the area has a regional gradient to the west-southwest (fig. 12). In at least two places the basement has had definite control over later sedimentation and structural developments, and the possibility for such control exists elsewhere. Some of the basement features can be correlated with structures in exposed parts of the adjacent shield area.

Considerable work has been done on the basement with regard to determination of its lithology. Burwash (1957) presented descriptions of the basement samples available at that time, 118 samples in all. In central Alberta, Garland and Burwash (1959) constructed a basement geologic map based on well control and gravity data. North of this area, Agarwal (1960) has recently completed a basement map based largely on aeromagnetic data and the sample descriptions of Burwash (1957) for that area.

A considerable number of age determinations have been completed on samples from the basement of this area. Burwash (1957) presented 18 K-Ar age determinations on whole rock samples. More recently mica and hornblende dates have been completed (Burwash, et al, 1962).

Basement Features.--The major basement features are shown on figure 13 and by the basement contours of figure 12. Regionally four features are most evident on the basement surface. In northern Alberta a buried positive feature is shown by the basement contours. This high is partly paleotopographic and partly structural in origin, and has been referred to as the Peace River ridge (Webb, 1954, p. 10). Its paleotopographic nature is indicated by the fact that it stood as a positive area until Upper Devonian time when it was innundated by seas. A similar high feature, the Sweetgrass arch, occurs in southern Alberta, and it is possibly continuous to the south as far as the Little Belt Mountain uplift of Montana. The basement surface lying between these two features shows an increasing gradient to the southwest

and the basement contours more or less parallel the eastern margin of the front ranges. The central Alberta basin is separated from the Williston basin by the Sweetgrass arch, Battle Creek saddle and North Battleford arch. The trough reflected in the basement contours north of the Peace River arch represents the Hay River basin (Van Hees, 1958, p. 77).

Faults in the basement rocks are known in some areas, and inferred in others where faulting has affected younger rocks. Haites (1960, p. 40, fig. 4) shows the major high angle faults of the western Canada area. Many of these in the plains area are thought to be the result of rejuvenation of Precambrian faults in Phanerozoic time. Faults of probable basement origin in northern Alberta strike northwest and northeast (Haites, 1960, p. 62; deMille, 1958, p. 67). The segmentation of the basement rocks into blocks provided the framework for later structural developments. DeMille (1958, p. 63) suggests that the Peace River arch . . . "rose differentially as a complex structure of fault blocks and was subsequently modified by long periods of erosion and adjustment to regional warping."

One of the major faults of this area which seems related to exposed shield structures is the Hay River fault (Haites, 1960, p. 40, fig. 4; Sikabonyi and Rodgers, 1959, p. 197). The Hay River fault is thought to be a continuation of the McDonald or East Arm fault occurring in the vicinity of the east arm of Great Slave Lake. Haites (1960, p. 41) points out that the total length of this feature including its extension into the subsurface is of the order of 650 miles.

Sproule (1957, p. 854) mentions the possibility of the extension of the Lake Athabasca structural trend of the shield into the basement area east of the Peace River ridge. This trend includes the northeasterly striking faults occurring north of Lake Athabasca in the Goldfields region. Somewhat south

of this general area, Garland and Bower (1959) have shown basement faults on the basis of aeromagnetic data (fig. 13). These occur with two main orientations, north-northwest and northeast, which seem to parallel known directions of faulting in the adjacent shield areas of Alberta and Saskatchewan.

The geologic literature concerning northern Alberta is extensive and the above discussion is only a summary of some of the available data. Much has been written with regard to the special structural features of the area and some authors discuss the importance of the basement in controlling these structures. For a more complete coverage of the area the reader is referred to the Alberta Society of Petroleum Geologists symposium on the Peace River area (1958) which contains a geologic bibliography of articles pertaining to the area (Macauley, 1958, p. 82-86).

In southern Alberta less is known about possible basement features mainly because of the greater depth to the Precambrian and the smaller number of wells penetrating basement. Haites (1960, p. 60-61) mentions the Drumheller fault and suggests right-hand displacement of one mile based on the apparent offset of a structure in Devonian rocks. He also mentions other signs of faulting in the plains region of southern Alberta but basement control has not been proven.

An interesting speculation mentioned by Goodman (1954, p. 353) who favors basement control as an important element in the development of younger structures in the plains region, is that the reef trends in central Alberta may be related to basement faulting. Mollard (1958, p. 115, fig. 10) makes the same speculation in saying that the linear trending oil fields in central Alberta which seem to fit a regional grid pattern are . . . "possibly related to major breaks in the crust that have periodically rejuvenated over the long course of geologic time." Recently Andrichuk (1961) has made similar suggestions.

Geophysical Data.--Available geophysical data for Alberta is somewhat limited. Aeromagnetic anomalies in north-eastern Alberta trend somewhat west of north and these are interpreted as being the result of bands of different compositions in the basement (Garland and Bower, 1959, p. 36). The southern part of the area is thought to be underlain by a basement composed of granitic rocks. From their study Garland and Bower (1959) were able to delineate some probable basement faults and these are shown in figure 13.

Garland and Burwash (1959) have interpreted gravity data for most of central Alberta. Using both gravity data and basement well control a lithologic basement map was constructed (Garland and Burwash, 1959). The authors point out (p. 806): "The pattern of gravity data is consistent with the concept of belts of gneissic rocks with a northeasterly trend, separated by more massive granitic bodies." The generalized trends of the anomalies are shown in figure 13.

Summary.--The basement surface of Alberta slopes to the west-southwest and has two major highs, the Sweetgrass arch and the Peace River ridge. In northern Alberta basement control on younger structures and sedimentational patterns, and correlation of basement structures with known shield structures are both evident. In northeast Alberta aeromagnetic data suggests basement faults, and a regional fabric with a northerly trend. In central Alberta the basement is fairly deep and basement structures are not known other than by geophysical methods. Gravity data has been interpreted to indicate northeasterly trending belts of different rock types. Systematic features such as reef trends may indicate basement control.

PETROLOGYPetrography

GENERAL STATEMENT

In the following section the results of the descriptive phases of this basement study are presented. A complete description of each sample occurs in the appendix, and photomicrographs of thin sections are shown on plates 1-9.

Standard methods of petrography were used in describing the core samples as well as the surface samples on which K-Ar dates were determined. One thin section from each sample was examined. Brief hand specimen descriptions were made in which the average or overall color of the rocks were estimated by comparison with the Rock Color Chart of the National Research Council (1948), and the general fabric of the rocks noted, in addition to any other pertinent features which were obvious in hand specimen. In thin section the average grain size of the rocks were estimated visually and the following classification used: coarse grained, >5 mm; medium grained, 1 to 5 mm; fine grained, <1 mm. This classification was used regardless of apparent origin.

With the use of a point counter a modal analysis was made for nearly all of the samples. The few slides not point-counted are either too fine-grained or highly altered to be counted accurately; the compositions of these samples were estimated visually. The modes were determined by counting grains intersected every 0.5 mm along traverses spaced 2 mm apart. Complete traversing of the thin sections using this spacing resulted in a count of approximately 500 points per slide. A greater number of points were counted where it was thought necessary. Unless the thin section was very inhomogeneous 500 points seemed sufficient for determining the compositions to the degree of accuracy

required. This was checked by calculating the cumulative mode at 100 point intervals during the course of point counting. In most slides the mode at 300 points was not appreciably changed by the additional 200 points except in terms of accessory minerals. Thus, the modes presented represent fairly accurately the volumetric compositions of the fine- and medium-grained, massive or homogeneous rocks. The modes given for the banded gneissic and coarse-grained rocks undoubtedly represent the composition of the thin section slice but leave much to be desired with regard to the composition of the core or hand specimen. Numerous thin sections of the same hand specimen would be necessary in order to determine the compositions of samples of this nature.

The compositions of the plagioclase feldspars must be known in order that the rocks be properly classified and these were determined by the extinction angle on albite twins in sections perpendicular to 010 and 001. (See Moorhouse, 1959, p. 58-60). The accuracy of this method is difficult to evaluate as the actual compositions are unknown. However, considering the fact that most of the rocks are plutonic and probably contain low temperature plagioclase, the determinations are probably fairly good. A histogram showing the results of the An determinations and thus the variation in plagioclase composition of the basement samples is given (fig. 15).

The problem of determining the origin of plutonic crystalline rocks is commonly difficult. It is even more difficult in a study of this nature because the field relations of the samples are not known. The only criteria available are the general features of the rocks themselves. The majority of the samples studied can, with a large degree of certainty, be classed as either metamorphic or igneous. Granitoid rocks with "massive" textures, containing typical igneous minerals are classed as igneous. Granitoid rocks

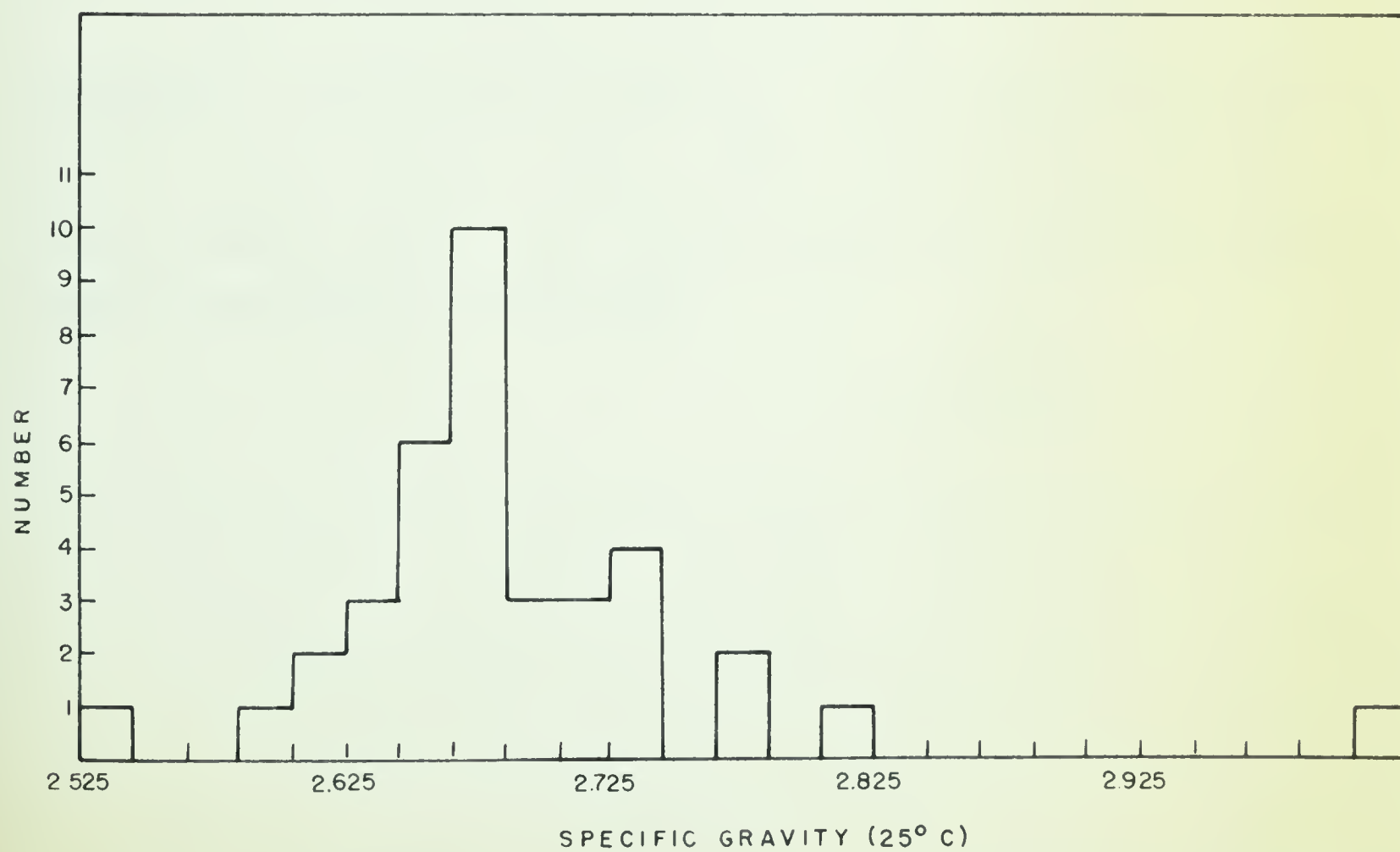
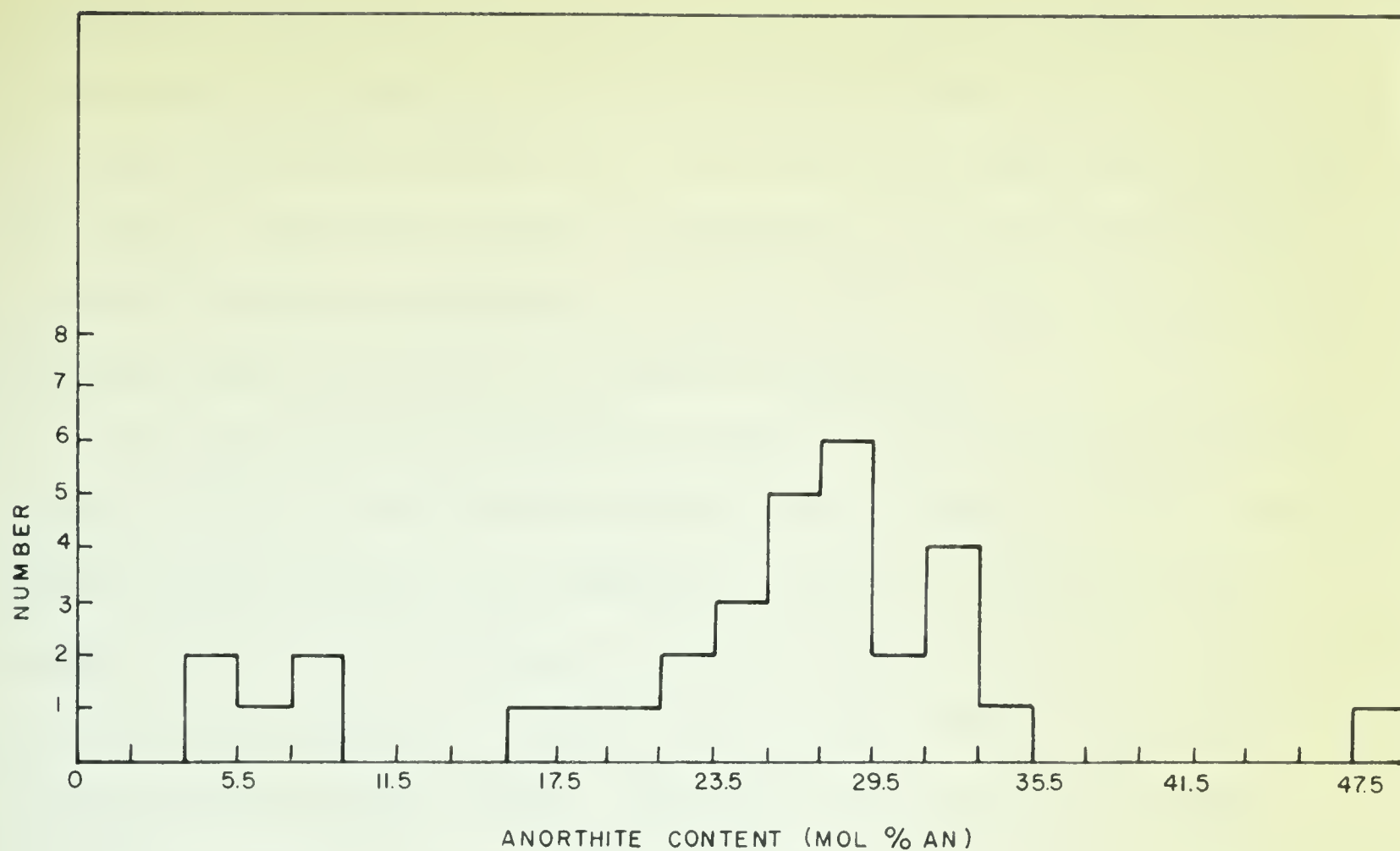


Figure 15.--Histograms of plagioclase compositions and specific gravities of basement samples.

exhibiting compositional banding and schistose rocks are classed without reservation as metamorphic. Between these two extremes there is a group of rocks which are not banded but foliated and have compositions that could be igneous. Mostly for the sake of conformity, foliated granitoid rocks are here classed as metamorphic. Admittedly this last grouping is arbitrary and some of the rocks are probably orthogneisses.

The classification of Moorhouse (1959) was used in naming the igneous rocks, as well as the numerical classification of Johannsen (1939). Rock names given by Moorhouse are modified by varietal or essential mineral names. Thus a quartz monzonite as given by Moorhouse, is called here a biotite quartz monzonite if biotite is a varietal mineral occurring in greater than accessory amounts. The terms gneiss and schist are used for the metamorphic rocks in the sense of Grout (1932, p. 358, 362). In the naming, the terms are preceded by the three or four most abundant minerals in increasing order of abundance.

No completely unmetamorphosed sedimentary rocks were encountered in the basement of Saskatchewan and Manitoba. The two samples representing the least-altered sedimentary rocks are 4221, a metaquartzite containing abundant epidote, and 4228 which consists of two phases, an arkosic meta-greywacke and phyllite or mica schist.

SPECIFIC GRAVITY DETERMINATIONS

Specific gravities of the core samples were determined (tables 11-12). The samples were first weighed on a triple beam balance and then weighed again while submerged in a beaker of water. This method takes no consideration of possible pore space and resulting buoyant force, but because of the crystalline nature of most samples, this possible error is negligible and the determinations are considered accurate to three significant figures. During the course of some ACF calculations a number of specific gravities were calculated from the modal compositions. The following comparisons between the calculated densities and the measured specific gravities are in good agreement.

Sample No.	(1) Density	(2) S.G.(measured)	Difference: (2)-(1)
4216	2.73	2.73	.00
4217	2.66	2.67	+.01
4225b	3.04	3.02	-.02
4225c	2.62	2.63	+.01
4226	2.72	2.71	-.01
4233	2.71	2.68	-.03
4235	2.68	2.68	.00
4237	2.84	2.80	-.04

Mean difference = [.02]

The agreement between these values is rather surprising for two reasons. Firstly, all of the above samples are interpreted as being of metamorphic origin and are somewhat inhomogeneous. Secondly, the thin section slice from which the densities were calculated represents only about 0.4 gram sample whereas samples on the order of tens and hundreds of grams were used

for the specific gravity measurements. The agreement is probably not entirely fortuitous and is a good check on the accuracy of the modal analyses.

A histogram of the specific gravities is given in figure 15. Only those samples which have not been affected by moderate or extreme chemical alteration are plotted. Five fresh samples are not plotted for the sake of not extending the diagram to the extreme values of 2.35 and 3.23; however, these values are used in the calculation of the mean specific gravity of the basement samples.

The mean specific gravity of the 39 measured core samples from Saskatchewan, Manitoba, and North Dakota is 2.68_5 . Burwash (1957) measured the specific gravities of 64 basement cores from Alberta and the mean value is 2.70_3 . The combined mean for the basement cores from the two areas is 2.69_6 . This value represents the average of 106 samples more or less randomly distributed over a very large area of Precambrian basement.

IGNEOUS ROCKS

Basement rocks from 17 wells are interpreted as having had an igneous origin and the modes of these are tabulated (table 11). All are acidic to intermediate in composition; no basic igneous rocks were encountered. From the limited data, two areas in the basement of Saskatchewan appear to have a concentration of igneous rocks. Six of the eight wells in southwestern Saskatchewan and four of the five wells in west-central Saskatchewan have penetrated igneous rocks. The igneous rocks are discussed by area, and more detailed discussion of the apparent distribution of these rocks is presented in a later part of this chapter.

Table 11.--Modes of igneous rocks.

Index No.	24	25	26	27	28	29**	1	3	4	5	17	20	21	30	32	38*	41
Sample No.	4229	4220	4230	3633	3634	2182	4222	2429	2428	2430	4213	2211	4236	4219	4234	4679	4680
Quartz	20	50	30	41	Tr	7.5	32	35	26	13	27	33	32	34	37	--	30
K-feldspar	43	18	46	31	10	14	27	41	40	27	20	]64	3.7	37	26	30	35
Plagioclase	33	23	11	20	8	7.2	34	22	28	34	?		63	25	33	--	30
Biotite	1.5	--	8.7	7.7	]5	2.4	3.5	2.0	Tr	13	13	2.0	0.1	2.1	2.9	Tr	2.1
Hornblende	--	--	0.5	0.3		--	--	--	0.8	10	--	--	--	--	--	Tr	--
Pyroxene	--	--	--	--	--	--	--	--	4.1	--	--	--	--	--	--	--	--
Muscovite	Tr	--	Tr	Tr	--	--	2.0	--	--	--	--	--	Tr	--	0.8	5	1.2
Apatite	Tr	Tr	0.2	Tr	Tr	--	Tr	--	0.4	Tr	Tr	Tr	--	Tr	--	--	Tr
Zircon	Tr	Tr	Tr	Tr	--	--	Tr	Tr	Tr	Tr	Tr	Tr	--	Tr	Tr	--	--
Mag.-Il.	1.4	--	1.2	0.3	Tr	--	1.0	0.7	Tr	1.0	Tr	Tr	1.7	Tr	--	--	1.8
Py. Pyrr.	--	--	--	--	--	--	--	--	Tr	--	5	--	--	--	--	--	--
Sphene	--	--	1.0	--	Tr	--	Tr	Tr	--	1.1	Tr	--	--	Tr	Tr	--	--
Epidote	1.7	Tr	Tr	0.8	Tr	0.7	--	--	Tr	Tr	--	--	--	Tr	--	--	--
Chlorite	3.0	8.5	0.5	Tr	--	--	Tr	--	Tr	--	]30	1.1	Tr	Tr	Tr	30	--
Sericite	--	--	--	Tr	Tr	2.6	--	--	Tr	--		--	Tr	--	--	30	Tr
Carbonate	Tr	--	--	Tr	Tr	--	--	--	--	--	6	--	Tr	Tr	Tr	5	Tr
Leucoxene	Tr	Tr	Tr	--	Tr	--	--	Tr	--	--	Tr	--	--	Tr	--	--	--
Fe oxides	Tr	0.2	--	--	--	--	--	Tr	--	--	--	Tr	Tr	--	Tr	Tr	Tr
Groundmass	--	--	--	--	77	65	--	--	--	--	--	--	--	--	--	--	--
Others	--	--	--	0.6	--	--	--	--	--	--	--	Tr	--	--	--	--	--
An content	4	8	5	7	?	9	21	17	24	28	?	19	25	34	25		28
Johnnansen No.	216"	213	216	216"	?	216"	127"	126"	226"	227"	?	?	127	126"	127"	?	126"
S. G.	2.63	2.64	2.67	2.66	2.69	2.64	2.66	2.61	2.65	2.73	2.58	2.61	2.55	2.66	2.63	2.67	2.64

*Mode by visual estimation

**Burwash (1957)

Southwestern Saskatchewan.--There is little doubt that six of the eight samples from this area are of igneous origin. The remaining two are sample 4221, a meta-quartzite, and samples 4231 b, -c, and -d. Samples 4231 b and -c are chemically altered beyond accurate identification. Sample 4231 d might possibly be of igneous origin but because it is crudely foliated and does not have a typical dioritic texture to go with its composition, it is assumed to be metamorphic.

The six igneous rocks from this area (2182, 3633, 3634, 4220, 4229 and 4230) are markedly different from the other basement igneous rocks. The modes of these samples are given in table 11. The most obvious characteristic of four of the six samples is their porphyritic texture, probably indicating a volcanic or hypabyssal origin. Samples 2182 and 3634 are both aphanite porphyries, and samples 3633 and 4230 are porphyritic phanerites. The other two samples, 4220 and 4229, are even-grained granites.

A similarity also occurs in the anorthite contents of these rocks. All, except perhaps 3634, on which an An determination is impossible because of alteration of the plagioclase, contain albite. This fact alone differentiates these rocks from the other basement igneous rocks, all of which contain oligoclase or andesine. This separate grouping of An contents is well shown in the histogram (fig. 15). With the exception of sample 4220, all six samples are classed as 216" or sodaclase adamellites or rhyolites depending on grain size.

The two aphanite porphyries, 2182 and 3634, are similar in some respects and different in others. Both contain phenocrysts of perthitic microcline and plagioclase. Sample 2182 contains composite phenocrysts of quartz whereas in 3634 all of the quartz is located in the groundmass. The groundmass of both samples consists essentially of a fine-grained mosaic of quartz and

K-feldspar with some mafic minerals. Sample 3634 contains both biotite and hornblende in the groundmass, in places as clots or segregations.

The two porphyritic phanerites are texturally and compositionally different. Sample 3633 consists of 30 to 40 per cent phenocrysts of feldspar and quartz up to 15 and 10 mm in size respectively, set in a fine- to medium-grained, equigranular groundmass. The quartz is blue in hand specimen and shows strong undulatory extinction in thin section. A typical association formed by the mafic and accessory minerals is biotite, magnetite, epidote, allanite, and hornblende. In places the allanite exhibits coronas of epidote. In general this rock is characterized by the presence of blue quartz phenocrysts and the unique occurrence, with respect to other basement igneous rocks, of fluorite and allanite as accessory minerals.

Sample 4230 is characterized by the extensive development of granophyric or graphic intergrowths of quartz and K-feldspar. The granophyre fills the interstices of the rock and is especially well developed along the borders of the K-feldspar phenocrysts which are up to 20 mm in length. The K-feldspar is strongly perthitic microcline which contains inclusions of all other minerals. In hand specimen the phenocrysts are characterized by their rounded appearance, and the individual quartz grains have a bluish tinge. Green biotite, hornblende, and accessory minerals are concentrated in segregations.

The remaining two samples, 4220 and 4229, are nonporphyritic, and similar to each other and the samples described above only in terms of plagioclase composition and alteration. Sample 4220 is a very coarse grained rock with feldspars up to 3 cm in diameter. Shearing is evidenced and veinlets of chloritic material cut the rock. The mafic minerals have been completely altered to chlorite but the feldspars, other than being coated with iron oxide, are fresh.

It is obvious from the hand specimen that the thin section mode does not represent the composition of the whole rock. An estimate from hand specimen gives 10 per cent mafic minerals, 15 per cent quartz, and the remainder feldspar. It is difficult to differentiate the two feldspars in hand specimen because of iron staining. The microcline is strongly perthitic and the plagioclase is anti-perthite of the patch variety.

Sample 4229 in hand specimen appears to be a very fresh rock, however, the thin section reveals some alteration. Sutured grain boundaries, undulatory extinction in quartz, and warped twin lamellae in the plagioclase indicate a post-crystallization deformation. Much of the biotite has altered to chlorite. Microcline is poikilitic but not intensely perthitic. The plagioclase has been moderately altered to sericite and stained with iron oxide. Samples 4220 and 4229 both appear to have undergone similar alteration, consisting of moderate cataclasis with associated chloritization of the mafic minerals and iron staining of the feldspars. The other four samples from this area have not undergone such alteration.

West-Central Saskatchewan.--The igneous rocks, 4222, 2428, 2429, and 2430 from this area contain plagioclase ranging in composition from An 17 to An 28. Sample 4222 is a quartz monzonite containing about equal amounts of plagioclase, quartz, and microcline. Biotite is the main mafic mineral with minor muscovite. As is typical in most of the basement igneous rocks the plagioclase is slightly altered, whereas the microcline is completely fresh. Sample 2428 is a rather unusual quartz monzonite in that hypersthene is the dominant mafic mineral. The essential minerals are microperthitic orthoclase, intermediate oligoclase, strained quartz, and hypersthene. Both biotite and hornblende are associated with the hypersthene and may be alteration products.

Myrmekite is developed at the contacts of plagioclase and orthoclase. All of the above features are characteristic of charnockites and this rock could be classified as such. Sample 2429 is a fine-grained, leucocratic granite of which 97 percent is composed of quartz, orthoclase, and plagioclase. Biotite is the main accessory but there are minor amounts of opaque minerals, zircon, and sphene. All these essential minerals show evidence of straining. Vein perthite and patch antiperthite are present. Sample 2430 is a very coarse-grained hornblende-biotite quartz monzonite in which feldspar grains attain a length of 1.5 cm. In places both hornblende and biotite are poikilitic with abundant inclusions of quartz. Microcline is perthitic and plagioclase is antiperthitic with some myrmekite at the borders. Opaque minerals, sphene, and zircon are abundant accessories.

Igneous Rocks from Other Areas.--Sample 4219 is a very coarse-grained quartz monzonite with feldspar grains up to 4 cm in length. Because of the grain size the mode reported in table 11 is an approximation of the composition. Microcline shows only crude quadrill twinning and is finely perthitic. Myrmekite is well developed between the quartz and feldspar grains. The plagioclase is sodic andesine. Except for the absence of hypersthene, this sample is somewhat similar to the hypersthene quartz monzonite (2428).

Sample 4236, an altered granodiorite, is an unusually small sample, 4 cm in diameter and about 2 cm in length. The rock is classified as igneous on the basis of the anhedral-granular texture as seen in thin section. Both microcline and oligoclase moderately altered and stained with iron oxide giving the rock a red color.

Quartz is strained and lined with bubble trails and dust inclusions. Biotite and fibrous intergrowths of chlorite occur in minor amounts.

Sample 4234 is a fine-grained, equigranular quartz monzonite containing essentially quartz, oligoclase, perthitic microcline, and biotite. The oligoclase is slightly zoned and in places the more calcic cores are dusted with alteration but the rim is fresh. There is little doubt about the origin of this rock; the composition is very close to that of the granite eutectic (fig. 21) and the texture is anhedral granular or aplitic.

Sample 4213 is a biotite granite which has undergone intense chemical alteration. It is a coarse-grained rock with feldspars up to 2 cm in length. Potash feldspar and biotite have escaped intense alteration. The K-feldspar is microperthitic and is probably microcline, although there is only a suggestion of grid-iron twinning. Mild cataclasis of many of the grains has occurred, and the fractures have been filled with carbonate and a low birefringent mineral which may be gypsum. Plagioclase grains have been altered to a mass of very fine-grained "clay mineral".

Sample 2211 is probably a hypersolvus microgranite or microgranodiorite. The feldspars seem to occur in three distinct phases: (1) perthitic masses in which one phase has been intensely altered to kaolinite or some other fine-grained mineral, (2) discrete grains of plagioclase, and (3) discrete grains of microcline. Phase (1) is by far the most abundant. Quartz occurs as somewhat larger grains than the remainder of the rock. Biotite has been altered to chlorite in part, and chlorite also occurs as small veinlets cutting the rock.

The remaining two igneous rocks are from wells in North Dakota. Sample 4679 is probably a syenite in which the mafics and plagioclase have been severely altered. The average grain size is about 4 mm although some of the orthoclase laths reach 5 mm in length and 2 to 3 mm in width. One of the main constituents, probably plagioclase, has been completely altered to sericite. Chlorite and hematite are the next most abundant alteration products. The rounded nature of some of the chlorite-hematite masses suggest that they are pseudomorphs after olivine.

Sample 4680 is a biotite quartz monzonite with about equal amounts of quartz, slightly perthitic microcline, and plagioclase. Quartz is strained, in places composite, and shows mutual suturing of grain boundaries. Plagioclase is slightly zoned and moderately altered to sericite. The biotite and magnetite grains are in places altered to hematite.

METAMORPHIC ROCKS

Twenty-five wells encountered basement rocks which are interpreted as having had a metamorphic origin. Four are wells drilled in Manitoba, three in North Dakota and the remainder in Saskatchewan. Rather than give a brief written description of each as was done with the igneous rocks, which were fewer in number and more unique, the modes and pertinent features are tabulated (tables 12 and 13). The order in which the samples are described is based on their locations taken from north to south. In the descriptive table the rock name, grain size and general texture, alteration subsequent to the main metamorphism, stable assemblage as deduced from thin section, and probable metamorphic facies are presented. Compositional banding is also indicated and if the term gneissic is used alone, banding is not conspicuous.

Table 12.--Modes of metamorphic rocks.

Index No.	2	6	7	7	7	7	7	8*	9*	9*	10	11	12*	13	13	13	14
Sample No.	4217	4226	4225a	4225b	4225c	4225d	4223	4227a	4227b	4224	4232	4228	4484	4485b	4485c	4215	
Quartz	27	22	39	2.3	31	29	30	30	15	41	24	50	32	31	43	33	
K-feldspar	28	21	9.0		35	27	20	--	Tr?	12	18	]20	--	--	--	25	
Plagioclase	33	42	39	31	30	40	--	--	--	Tr	40		--	--	4.1	--	--
Biotite	9.3	8.6	13	0.7	1.7	3.6	20	5	25	33	15	--	8.3	23	20	22	
Hornblende	--	4.3	--	61	--	--	--	--	--	--	--	--	3.3	--	--	--	
Pyroxene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Muscovite	Tr	--	--	--	--	--	--	--	--	6.0	--	Tr	Tr	--	--	17	
Garnet	--	--	--	--	--	--	10	--	Tr	--	--	--	--	--	--	Tr	
Sphene	--	Tr	--	2.0	--	Tr	Tr	--	--	--	Tr	--	--	--	--	Tr	
Apatite	0.2	0.4	Tr	0.4	Tr	--	Tr	Tr	Tr	Tr	0.6	Tr	--	--	--	Tr	
Zircon	0.1	--	Tr	--	Tr	Tr	Tr	--	--	Tr	Tr	Tr	--	--	--	Tr	
Mag.-Il.	0.2	0.3	--	0.8	--	--	Tr	Tr	--	Tr	--	--	51	0.4	31	]3	
Py.-Pyrr.	--	--	--	0.8	--	--	--	--	--	0.7	--	--	--	--	--		
Tourmaline	--	--	--	--	--	--	--	--	--	Tr	--	Tr	--	0.6	--	Tr	
Chlorite	1.0	0.3	--	1.2	0.1	Tr	Tr	Tr	--	--	0.4	--	--	Tr	--	Tr	
Carbonate	0.5	0.2	--	Tr	Tr	Tr		25	5	7.4	1.4	--	--	5.5	40	6.4	Tr
Sericite	Tr	Tr	Tr	Tr	Tr	Tr	Tr	--	--	--	1.4	--	--	--	--	--	
Fe oxides	--	--	Tr	Tr	Tr	Tr		Tr	--	Tr	--	--	--	--	--	--	--
Leucoxene	Tr	1.3	Tr	0.4	--	--	Tr	Tr	--	--	0.2	--	--	--	--	--	
Groundmass	--	--	--	--	--	--	Tr	40	55	--	--	30	--	--	--	--	
An Content	22	32	26	48	28	27	--	--	--	--	28	--	--	--	--	--	
S. G.	2.67	2.71	2.66	3.02	2.63	2.64	2.38	2.43		2.77	2.66	2.35	3.49	2.88	3.25	2.70	

*Mode visually estimated

Table 12.--Modes of metamorphic rocks

Index No.	15	16	18	19*	22*	22	23*	31	33	34	35	36	39	40	42
Sample No.	4237	4238	4677	4218	4231b	4231d	4221	4483	4214	4216	4233	4235	4678	4682	4681
Quartz	28	33	31	50	20	15	90	45	3	31	31	28	25	35	30
K-feldspar	--	16	38	--	--	--	--	29	--	--	5.5	14	30	4.4	--
Plagioclase	14	42	24	Tr	--	56	--	14	--	52	48	49	32	50	56
Biotite	38	5.4	5.0	10	15	12	--	0.2	1	15	13	6.0	1.4	6.6	8.8
Hornblende	--	--	--	--	--	14	--	--	--	0.7	--	0.8	1.2	--	0.4
Pyroxene	--	--	--	--	--	--	--	--	--	--	--	--	5.8	--	--
Muscovite	--	2.6	--	--	--	--	--	--	--	--	0.7	--	--	--	--
Cordierite	13	--	--	--	--	--	--	10	--	--	--	--	--	--	--
Sillimanite	4.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Garnet	0.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Epidote	--	--	Tr	--	--	Tr	9	--	--	2.0	0.8	1.9	--	0.4	3.6
Sphene	--	--	--	Tr	--	--	--	--	Tr	--	Tr	0.7	--	Tr	0.4
Apatite	Tr	Tr	0.4	--	Tr	Tr	--	--	Tr	0.1	Tr	Tr	0.6	0.2	0.4
Zircon	Tr	Tr	Tr	--	Tr	Tr	--	Tr	--	Tr	Tr	--	Tr	0.2	Tr
Mag.-Il.	--	--	--	--	Tr	0.6	--	--	1	--	Tr	Tr	1.4	--	--
Py.-Pyrr.	1.0	--	10.8	--	--	--	--	--	--	--	--	--	--	0.6	0.4
Chlorite	--	Tr	0.4	--	Tr	1.6	--	--	1	0.3	1.0	Tr	2.0	1.8	--
Carbonate	--	--	1.0	10	10	Tr	1	--	--	--	Tr	--	0.4	0.2	Tr
Sericite	--	Tr	--	30	--	0.8	--	1.3	--	Tr	--	--	Tr	0.2	--
Iron oxides	--	--	Tr	--	Tr	--	--	--	--	--	--	--	Tr	--	--
Leucoxene	--	--	--	Tr	Tr	--	--	--	Tr	--	Tr	--	--	--	--
Groundmass	--	--	--	--	55	--	--	--	93	--	--	--	--	--	--
An content	32	27	30	--	--	32	--	27	--	28	32	27	30	27	23
S. G.	2.80	2.64	2.66	2.53	2.77	2.77	2.71	2.58	2.28	2.73	2.68	2.68	2.72	2.66	2.73

Table 13.--Descriptive data for metamorphic rocks

Sample No.	Rock Name	Grain Size Texture	Alt.	Stable Assemblage	Facies
4217	Bio.-qtz.-fd. gneiss	medium banded gneissic	C+ P-	q-mi-ol-bi	AA
4226	Hbl.-bio.-qtz.-fd. gneiss	medium to coarse porphyroblastic gneissic	C+ P-	q-mi-an-bi-ho	AA
4225a	Bio.-qtz.-fd. gneiss	fine banded gneissic	C+ P-	q-mi-ol-bi	AA
4225b	Plag. amphibolite	fine granoblastic	C+ P-	q-an-ho	AA
4225c	Bio.-qtz.-fd. gneiss	medium gneissic	C+ P+	q-mi-ol-bi	AA
4225d	Bio.-qtz.-fd. gneiss	medium gneissic	C+ P+	q-mi-ol-bi	AA
4223	Garnet-bio.-fd.-qtz gneiss	medium banded gneissic	C+++ P++	q-or-bi-g	AA or UG
4227 (a,b)	Bio-qtz. gneiss	fine to medium banded gneissic	C+++ P++	q-bi-g	AA or UG
4224	Fd.-qtz.-mica schist	fine lepidoblastic	C+ P-	q-or-bi-mu-cc	AA or UG
4232	Bio-qtz.-fd. gneiss	medium to coarse banded gneissic	C++ P-	q-mi-ol-bi	AA
4228	Phyllite and meta-greywacke	fine lepidoblastic and clastic	C- P-	q-mu-bi-mi(?)	UG
4484	Iron formation	fine banded	C- P-	q-bi-mt-cc-ho) (	
4485b	Bio.-qtz. marble	fine banded	C- P-	q-bi-cc) (	AA or UG
4485c	Iron formation	fine lepidoblastic	C- P-	q-bi-mt-cc)	
4215	Musc.-bio. schist	fine lepidoblastic	C+ P-	q-mi-mu-bi	AA or UG
4237	Cordierite-qtz-bio. schist	fine lepidoblastic	C+ P-	q-an-co-si-g	Trans AA
4238	Musc.-bio.-qtz.-fd. gneiss	fine to coarse banded gneissic	C+ P-	q-mi-ol-bi-mu	AA
4677	Bio.-qtz.-fd. gneiss	fine gneissic	C+ P+	q-mi-ol-bi	AA
4218	Calcareous qtz.-mica schist	fine lepidoblastic	C+ P-	q-mu-bi-cc	UG
4231b	Chl.-bio. schist	fine lepidoblastic	C+++ P++	q-bi-chl	UG or AA
4231d	Bio.-hbl.-qtz.-fd. gneiss	fine banded gneissic	C+ P+	q-an-bi-ho	AA

Table 13.--Descriptive data for metamorphic rocks. (cont'd)

Sample No.	Rock Name	Grain Size Texture	Alt.	Stable Assemblage	Facies
4221	Metaquartzite	fine granoblastic	C- P-	q-ep	G or AA
4483	Cordierite-qtz-fd gneiss	medium faintly gneissic	C+ P++	q-mi-ol-co-bi	Trans AA
4214	Bio.-qtz. rocks	fine faintly lepidoblastic	C+++ P++	q-bi (?)	UG ?
4216	Bio.-qtz.-fd. gneiss	medium gneissic	C+ P-	q-ol-bi-ho-ep	AA
4233	Bio.-qtz.-fd. gneiss	medium banded gneissic	C+ P+	q-an-mi-bi-mu-ep	AA
4235	Bio.-qtz.-fd. gneiss	fine gneissic	C- P-	q-mi-ol-bi-ho-ep	AA
4678	Hyp.-qtz.-fd. granulite	fine granoblastic	C++ P++	q-mi-ol-hy-ho(?)	PG
4681	Epidote-bio.-qtz.-fd. gneiss	fine gneissic	C- P-	q-ol-bi-ep	AA
4682	Bio.-qtz.-fd. gneiss	fine to medium banded gneissic	C+ P-	q-mi-ol-bi-ep	AA

Explanation

Alteration:

C chemical
P physical
- nil
+ minor
++ moderate
+++ intense

Stable assemblage:

q	quartz	ho	hornblende
ol	oligoclase	hy	hypersthene
an	andesine	co	cordierite
mi	microcline	si	sillimanite
or	orthoclase	g	garnet
mu	muscovite	ep	epidote
bi	biotite	cc	carbonate

Facies:

PG pyroxene granulite
AA almandine-amphibolite
UG upper greenschist (includes quartz-albite-epidote-biotite, and quartz-albite-epidote-almandine subfacies).
G greenschist undivided
Trans AA transitional from conditions of hornblende hornfels to almandine amphibolite facies (Fyfe, Turner, and Verhoogen, 1958, p. 211).

A two-fold classification of alteration is given: physical and chemical. Physical alteration refers to mechanical dislocation or cataclasis of the rock. Evidences in thin section such as strained, bent, or fractured grains; mortar structure; crushed or sheared zones; and others are used for the recognition of physical alteration. Such features as sericitization or saussuritization of feldspars; chloritization of biotite, amphibole or pyroxene; uralitization of pyroxene; and others suggest chemical alteration. The alteration of both types is arbitrarily classed as minor, moderate, or intense. Minor alteration would be indicated by slight sericitization of feldspars or slight chloritization of biotite. Slight fracturing of quartz or bending of plagioclase twin lamellae indicates minor physical alteration. Intense chemical alteration could be nearly complete alteration of one or more minerals. Major crushing and shearing would suggest intense physical alteration.

The facies classification as modified by Fyfe, Turner and Verhoogen (1958) is used. For some samples, determination of the metamorphic facies is difficult. Many of the rocks are probably derivatives of quartzo-feldspathic parents and because of this the stable assemblage is not especially definitive with regard to subfacies. The plagioclase-bearing rocks are readily classed as either greenschist or almandine-amphibolite facies on the basis of An content of the plagioclase. The composition dividing the two facies is taken at An 10 (Fyfe, Turner and Verhoogen, 1958, p. 218). For each rock the highest recognizable facies is given; some samples contain chlorite and other low grade minerals which may indicate retrograde metamorphism.

Several of the samples are so highly altered that identification of a stable assemblage is practically impossible. Samples 4223, 4227, 4231b and

4214 have all undergone considerable alteration. The first three of these samples are definitely metamorphic rocks with later imposed alteration. Sample 4214 could possibly be an igneous rock that has undergone low grade metamorphism or merely alteration due to weathering.

Interpretive Petrology

GENERAL STATEMENT

The results of the descriptive phase of the petrologic work, suggest certain tentative conclusions. In figure 12 symbols representing different rock types are plotted at the appropriate well locations. General statements can be made with respect to abundances of the different rock types and their areal distribution, comparisons with the adjacent shield areas, and grade of metamorphism.

AREAL DISTRIBUTION AND ABUNDANCES OF ROCK TYPES

Meek (1958) examined both basement core and chip samples from Saskatchewan and Manitoba and constructed a generalized basement geologic map. After examining 105 samples he concluded that most of the basement is composed of acid igneous rocks and the areas not dominated by these are east-central Saskatchewan and southwestern Manitoba.

Tullis (1952) compiled descriptions of core and chip samples from North and South Dakota and Montana. Of the 26 samples, he interpreted 15 as granite or related rock types, four as intermediate or basic metamorphosed igneous rocks, one as a mixture of granite and amphibolite, and the others as quartzites, schists, and rocks of uncertain origin. He notes (p. 39) that all of the granitic igneous rocks are gneissic; therefore, the results are not directly comparable to the present study as different criteria were used in determining origins.

The results of the present detailed study of samples from 43 basement wells suggest that the basement is composed mainly of metamorphic rocks; 25 wells encountered metamorphic rocks and the remainder, igneous rocks. If field evidence were available the number of rocks interpreted as metamorphic might be slightly reduced but they would still likely equal or exceed the number of igneous rocks.

The conclusions concerning the areal distribution of metamorphic rocks (fig. 12) are essentially the same as those of Meek (1958). The four samples from southwestern Manitoba are interpreted as being metamorphic, although sample 4214 could possibly be an altered igneous rock. Two areas in Saskatchewan appear to have concentrations of metamorphic rocks. Between Dore and Montreal Lakes there is a line of five wells of which four have penetrated gneiss and one, schist. A well south of this line also encountered gneiss (4232). Approximately 60 miles east of Prince Albert six wells have penetrated a basement composed of schists and metasediments. The apparent concentration of metamorphic rocks in these two areas is consistent with the adjacent shield geology.

The majority of the basement metamorphic rocks are quartzo-feldspathic gneisses having compositions similar to acidic and intermediate igneous rocks. Mica schists and metasediments occur in lesser amounts. Thirteen of the metamorphic rocks are gneisses with quartz and feldspars forming the main framework and biotite and/or hornblende comprising the mafic phase. One well from which four samples are available (4225a,b,c,d) penetrated an amphibolite (4225b) as well as quartzo-feldspathic gneisses (4225a,c,d). A pyroxene granulite was encountered in North Dakota located near the center of the Williston Basin. Schists and metasediments comprise the remaining basement metamorphic samples. Five of the samples have undergone moderate to intense

chemical alteration probably as a result of weathering. Three of these are from central Saskatchewan and the alteration may be the result of exposure during late Precambrian or early Paleozoic time.

With regard to grade of metamorphism, 14 wells encountered rocks definitely belonging to the almandine-amphibolite facies. Ten wells penetrated rocks of either the upper greenschist, above the biotite isograd, or almandine-amphibolite facies of which three are probably in the greenschist; and one well penetrated a pyroxene granulite.

Two areas, both in Saskatchewan, appear to be underlain by basement in which igneous rocks are abundant. Six of eight samples in southwestern Saskatchewan are igneous and have similar compositions. All of the porphyritic rocks are from this area. These are suggestive of emplacement at a fairly high level in the crust. Granophyre in sample 4230 suggests emplacement in the epizone (Buddington, 1959, p. 679). Helium occurring in the B. A. Wilhelm well (Sawatzky, Agarwal, and Wilson, 1960) may possibly be related to the radioactive allanite in sample 3633 from the adjacent basement well.

Four of the five most westerly wells in west-central Saskatchewan have penetrated igneous rocks--one granite and four quartz monzonites. Because of the small number of wells, the suggestion that the basement is dominantly igneous is not as convincing as in southwestern Saskatchewan and the apparent concentration may be fortuitous. However, geophysical data for this area is consistent with a dominantly granitic basement (Agarwal, 1961).

COMPARISONS WITH ADJACENT SHIELD AREAS

A statistical comparison has been made of the abundances of rock types from the basement and adjoining parts of the shield from within the Churchill province. Twenty-eight maps on a scale of one inch to one mile or larger were point counted of which twenty-one

the maps are from Saskatchewan and seven from Manitoba. A half inch grid system was constructed on a transparent overlay and placed on the maps. The rock unit at the intersection of each line on the grid was counted and tabulated. These units were then recalculated into a standard classification for comparative purposes. The maps, topographic coordinates, and coverage area in square miles are given below. The basic data are given in the Appendix C.

Table 14.--Map areas used for comparative purposes with basement samples.

Map Area	Location	Area (sq mi)
Crackingstone	74N, W7	151
Goldfields-Martin Lake	74N, E7,E10,W8,W9	503
Charlebois Lake	74P, 7	219
Middle Foster Lake	74A, NW11	100
Waddy Lake	64D, SW5, NE4	201
Windrum Lake	74A, E1	167
Settee Lake	73P, E16	169
Stanley	73P, E7, W8	337
Reindeer River	63M, S(1/4)14, 11	398
Manawan Lake	63M, N6	183
Deschambault Lake	63L, E14	167
Hanson Lake	63L, NW10	86
Mari Lake	63M, E1	172
Amisk-Wildnest Lakes	63L, 9, 16	702
Lynn Lake (Manitoba)	64C, E14, 15, 16 10, 11, 12	1688
	Total Area	5229

The scheme of classification of map units and basement rock samples is shown below:

1. Sedimentary, metasedimentary rocks, and derived schists--generally with low-grade metamorphism, but may include higher grade metamorphic rocks if they are obviously of sedimentary origin because of compositional or relict features such as cross-bedding, graded-bedding, clastic texture, etc.
2. Volcanic, metavolcanic rocks, and derived schists--same restrictions as for (1) except relict features would be characteristic of volcanic rocks.
3. Silicic to intermediate plutonic rocks (granitic to dioritic composition inclusive).
 - 3a. Igneous origin probable
 - 3b. Metamorphic origin probably--mostly paragneisses and migmatites
4. Mafic plutonic rocks (gabbroic to ultrabasic in composition--generally more than 40 per cent mafic minerals and/or greater than An 50 for plagioclase composition).
 - 4a. Igneous origin probable
 - 4b. Metamorphic origin probable--high-grade derivatives of basic volcanics and basic sedimentary rocks such as impure marbles.

Though the divisions of this classification are arbitrary it is the most logical classification for the comparison of rocks from the shield and from the basement. Initially an attempt was made to divide the metasediments (1), and metavolcanics (2), from the plutonic rocks (3) and (4) on the basis of grade of metamorphism. The dividing line was placed at the boundary between the greenschist and amphibolite facies. This division was found to be unsatisfactory because some rocks are recognizable as metavolcanics and metasediments even though they may have undergone moderate grades of metamorphism. For example, a conglomerate or quartzite may have been metamorphosed in the amphibolite facies but because of composition or obvious sedimentary features they may still be recognizable as metasediments, and would undoubtedly be classified as such in the field. The division may not be as absolute as one based on an isograd but it is more realistic in terms of field mapping. Undoubtedly some of the units have been wrongly classified

but it is hoped that any inconsistencies will be averaged out in the final compilation of abundances.

The maps studied represent about 1/17 of the shield area of Saskatchewan and the adjoining Lynn Lake district of Manitoba. It is assumed, if the map-areas were randomly distributed, that a sampling factor of 1/17 would be adequate to provide a reasonable estimate of the lithologic composition of this shield area. Because of the presence or possibility of mineral deposits there is a tendency for certain areas to be mapped, and this has resulted in a bias towards the Lynn Lake and Amisk-Wildnest Lakes areas. Another major bias inherent in this study is the influence of lithology on glacial erosion. Lakes, swamps, and glacial cover average 23 per cent of the areas studied, and if these covered areas are underlain by softer rock types, such as metasediments, then there is a considerable bias in the final calculated rock type abundances. This possibility is difficult to evaluate or correct, however, it is hoped that the results give a good approximation, if not an absolute picture, of abundances of rock types in this shield area.

An attempt was made to classify the basement rocks so a comparison can be made with abundances determined for outcrop areas. The main difficulty results from the lack of any large scale features which might be useful in facilitating a determination of origin. In field mapping many interpretations may be based for a great part on features seen in outcrop and not necessarily on the petrography of any one sample from the outcrop. Even so many of the basement samples can be classified with some degree of certainty. In the following list a question mark follows those sample numbers for which classification of the samples is not too certain.

1. Metasediments: 4215, 4224, 4237?, 4228, 4221, 4484, and 4485 (the last two are counted as one because of their proximity)
2. Metavolcanics: 2182, 3634, 4218?
3. Silicic to intermediate plutonic rocks:
 - a. Igneous rocks: 3633, 4230, 4229, 4220, 4222, 2428, 2429, 2430, 4219, 4236, 4213, 4679, 3798.
 - b. Metamorphic rocks: 4217, 4226, 4225(a,c,d), 4223, 4227, 4232, 4528, 4231(b,d), 4483, 4677, 4678.
4. Mafic plutonic rocks:
 - a. Igneous rocks: none
 - b. Metamorphic rocks: 4225b, 3798.

Abundances of basement rock types are given in percentages and compared with both abundances from the different map blocks and the overall weighted average in table 15. For the shield areas, variations among the different units are great, especially (1), (2), and (4b). However, there are some striking conformities. Unit 4a is consistently low from area to area ranging from 0 to 3.7 per cent. The abundances of silicic to intermediate plutonic rocks (3a and 3b) shows good agreement. The overall weighted average for this combined unit is 60.6 per cent and the range from different areas is between 57.2 and 75.8 per cent.

The agreement between the abundances of basement rock types with the overall weighted average for the exposed shield is rather good. The comparison between metasediments and metavolcanics is good as is a comparison of combined silicic to intermediate plutonic rocks. The basement plutonic igneous rocks are lower than the average and the metamorphic rocks are higher. This is probably because of the difficulty in interpreting the origin of gneissose rocks without the benefit of field evidence. The basement rock abundances are much closer to the overall weighted average

Table 15.--Percentage distribution of rock types of the shield and basement.

Unit	A.	B.	C.	D.	E.	F.	G.	Avg*	Basement
1.	24.2	12.4	41.9	9.0	15.7	11.5	21.7	17.1	17
2.	0.8	----	----	22.6	0.7	20.5	5.2	10.0	8
3a.	51.6	70.4	22.8	42.0	51.0	38.2	52.6	47.5	39
3b.	8.6	5.4	34.4	24.4	11.6	19.5	5.1	13.1	30
3a.+3b.	(60.2)	(75.8)	(57.2)	(66.4)	(62.6)	(57.7)	(57.7)	(60.6)	(69)
4a.	0.3	----	----	1.6	3.7	3.2	3.3	2.5	----
4b.	13.9	12.1	0.9	0.3	17.2	7.1	12.1	9.6	6

Key to Areas:

A. Goldfields, Crackingstone

D. Waddy, Windrum, Settee Lakes, Stanley

B. Charlebois Lake

E. Manawan Lake, Reindeer River

C. Middle Foster Lake

F. Deschambault, Hanson, Mari, Amisk-
Wildnest Lakes

G. Lynn Lake

Units:

1. Sedimentary and metasedimentary rocks

2. Volcanic and metavolcanic rocks

3a. Silicic to intermediate igneous rocks (plutonic)

3b. Silicic to intermediate metamorphic rocks (plutonic)

4a. Mafic igneous rocks (plutonic)

4b. Mafic metamorphic rocks (plutonic)

* Weighted average according to areal coverage of maps.

than to the values for any particular area. This is to be expected because of the very large area represented by the basement samples. The limited data suggests that the basement of Saskatchewan and adjacent areas is comprised of rock types similar in abundances to those of the adjacent shield. If more samples become available from the basement, this similarity would probably be enhanced.

The basement samples from the northerly group of wells are the most amenable to distribution comparisons with the adjacent shield rocks. As mentioned before, there appear to be three areas in which certain rock types are most abundant. At the western end of the sample line granitic rocks seem to predominate, in the central part gneissic rocks are dominant and in the eastern part schists and metasediments are most abundant (fig. 12). The best means of comparison with the adjacent shield is by inspection of the Geological Map of Saskatchewan (Canada Geol. Survey, 1947). The prevailing strike of rocks near the edge of the shield is northeast except in east central Saskatchewan where the regional structures are complex. By projecting the strikes of the exposed rocks to the southeast it is found there is agreement between the major rock types in the shield and those in the basement. In the shield, west of 106 degrees, the predominant map unit is composed chiefly of acidic intrusive rocks. A projection of these rocks fits well with the granitic rocks of the basement. East of this area in the vicinity of Lac la Ronge, the main unit is a complex of sedimentary, volcanic, and intrusive rocks. More detailed maps shows this unit to be composed of schists, gneisses, arkoses, and associated metasediments that have been metamorphosed to a moderate grade. The gneissic rocks of Dore and Montreal Lakes are on strike with these gneisses of Lac la Ronge.

In east central Saskatchewan it is difficult to project the shield rocks because of the complexity of structure, however, there are similarities

between the exposed rocks and those found in the basement approximately 100 miles to the south. For comparative purposes the basement rock types are listed below.

Sample No.	Rock Type	Probable Parent
4215	Muscovite-biotite schist	Pelite
4228	Phyllite and metagreywacke	Pelite and greywacke
4237	Cordierite-qtz.-bio. schist	Pelite
4238	Muscovite-bio.-qtz.-fd. gneiss	Pelite or arkose
4485 and 4484	Iron formation	Iron formation (in part calcareous)

In Hanson, Deschambault, and Amisk-Wildnest map areas there are paraschists very similar to those mentioned above. Byers and Dahlstrom (1954) estimated 4000 feet of greywacke, minor argillite, quartzite, conglomerate, interbanded volcanics, and derived schists and gneisses in the upper part of the Amisk group; and 5000 feet of arkose, greywacke, and associated sediments in the Missi series occurring in the Amisk-Wildnest Lakes area. Byers (1957) has identified similar Amisk rocks in the Hanson Lake area. In the Deschambault Lake area metamorphism has been more extreme but the paraschists have in part had pelitic parents. It is interesting to note that in the Hanson and Deschambault Lake areas, schists containing cordierite and sillimanite are not uncommon. Iron formation is present in the sedimentary facies of the Amisk group in the Hanson Lake area (Byers, 1957).

The above similarities between exposed shield rocks and basement samples to the south are by no means conclusive evidence that the Amisk-Missi rocks extend 100 miles south in the basement. Such a regional correlation based solely on rock types is extremely hazardous and further samples would be necessary from the area between the outcropping rocks and the area from

which basement samples are available before any correlation could be proven or disproven.

In summary, the basement rocks of Saskatchewan are similar in type and relative abundance to the rocks exposed on the adjacent shield. The distribution of rock types in the northerly line of basement samples is similar to the distribution of rock types from the bordering shield area.

RADIOACTIVE DATINGIntroduction

In order that any radioactive decay scheme be usable for measuring geologic time several basic requirements must be fulfilled. These listed below are given by Rankama (1954, p. 110):

- (1) "The rate of decay of the radioactive nuclide must be known.
- (2) The sampling must be representative of the mineral or rock, and the analytical measurements involved in the age determination must be accurate.
- (3) The end product of decay and nonequilibrium amounts of any radio-nuclides intermediate between parent and the end product must be absent as primary constituents of the material analyzed.
- (4) No gain or loss of the end product of decay or its active source must have occurred during the history of the material, such as is produced by the alteration that causes interruption of radioactive equilibrium by external processes.
- (5) The isotopic constitution of the radioelement in the material from which the sample was formed must have been the same as the isotopic constitution of the radioelement in the uppermost lithosphere."

As is discussed later, requirement (3) is not always satisfied by minerals dated by the Rb-Sr method and attempts are made to accurately correct for the common strontium present in the system.

All of the age determinations completed at the University of Alberta for the present study were done by the K-Ar method. The Rb-Sr dates on

feldspars were done by the U.S. Geological Survey in Washington, D.C. The dates quoted from the literature are recalculated in terms of the constants used here. In the following section brief discussions of the fundamentals of the K-Ar and Rb-Sr methods are made. Following this a more thorough review is presented on the methods of mineral separations, potassium analyses, and argon analyses. An attempt is also made to discuss the various analytical and geological errors inherent or possible in the methods employed.

Methods

GENERAL DISCUSSION

K-Ar Geochronometer.--The isotopes of naturally occurring potassium are K^{40} , K^{41} , and K^{39} of which K^{39} is by far the most abundant. The isotope with mass 40 is unstable and decays radioactively to Ar^{40} and Ca^{40} . This decay results in the production of about eight times as much Ca^{40} as Ar^{40} . The disintegration of K^{40} to Ar^{40} is the basis of the K-Ar method of age determination. The K-Ca decay scheme has not been used to any great extent as a chronometer because of the abundance of common Ca^{40} in nature. (See Rankama, 1954, p. 312-314). Ar^{40} is the most abundant isotope of atmospheric argon and thus it is necessary to extract the radiogenic argon from the mineral in a system essentially free of air.

The decay of K^{40} to Ca^{40} takes place by the method of beta decay. An electron is spontaneously emitted from the nucleus in the form of beta radiation and the resulting nuclide is Ca^{40} .

The formation of Ar^{40} from the decay of K^{40} involves the capture of an electron from the K-orbital shell by the nucleus and thus the process is referred to as K-capture. The electron combines with a proton in the nucleus to form a neutron and Ar^{40} is formed. The Ar^{40} atom is in an "excited state"

because the K-orbital electron shell is not filled. An electron from an outer shell drops into the K-shell and gamma radiation is emitted because of the change in energy level of the electron.

Any radioactive decay scheme follows the first-order reaction rate law which can be stated as follows.

$$dN/dt = -\lambda N$$

This equation states that the rate of disintegration (dN/dt) of a radioactive nuclide is directly proportional to the amount of the nuclide present at that particular time. In other words it gives the slope (dN/dt) of the decay curve obtained by plotting the amount of the nuclide present versus time. The constant of proportionality (λ) is referred to as the decay constant. Since the slope of the curve is given by the above formula, the formula for the curve can be obtained by integration:

$$\int dN/N = -\lambda \int dt \quad \text{or} \quad \ln N/N_0 = -\lambda t \quad (\text{since } t_0 = 0)$$

where: N_0 = number of parent atoms present at $t = 0$

N = number of parent atoms present at time = t

From these fundamental relations it can be shown by simple derivation that the following function is obtained for the K-Ar decay scheme.

$$t = \frac{1}{\lambda} \ln \left(\frac{Ar^{40}}{K^{40}} \times \frac{\lambda}{\lambda_e} + 1 \right)$$

where: λ = total decay constant = $(\lambda_e + \lambda_\beta)$

λ_e = decay constant for K-capture decay

λ_β = decay constant for beta decay

By substitution of the appropriate constants and converting natural logarithms to common logarithms the final age formula is obtained.

$$t \text{ (years)} = 4.308 \times 10^9 \log (1 + (\text{Ar}^{40}/\text{K}^{40})(9.08))$$

The constants used for the K-Ar method are:

$$\lambda_e = 0.589 \times 10^{-10}/\text{yr}$$

$$\lambda_p = 4.761 \times 10^{-10}/\text{yr}$$

$$\text{K}^{40}/\text{K} = 0.0118_1 \text{ atomic per cent}$$

During the course of argon extraction from a mineral a known volume of spike argon is added to the radiogenic argon derived. The spike argon, although considerably enriched in Ar^{38} , does contain some Ar^{40} and Ar^{36} , and the composition must be accurately known in order that the necessary corrections can be made in the initial calculations. The spike argon used for the determinations presented here has the following compositions depending on which spike was used.

Spike Set I to X inclusive:

$$\begin{aligned} \text{Ar}^{36}/\text{Ar}^{38} &= 0.00121 \\ \text{Ar}^{40}/\text{Ar}^{38} &= 0.239 \end{aligned} \quad \left. \begin{array}{l}) \\ (\end{array} \right\} \pm 1 \text{ per cent}$$

Spike Set XI to XXX inclusive:

$$\begin{aligned} \text{Ar}^{36}/\text{Ar}^{38} &= 0.00034 \\ \text{Ar}^{40}/\text{Ar}^{38} &= 0.075 \end{aligned} \quad \left. \begin{array}{l}) \\ (\end{array} \right\} \pm 6 \text{ per cent}$$

Rb-Sr Geochronometer: The method used for the Rb-Sr dates reported has been described by Goldich et al (1961, p. 21-25). Naturally occurring rubidium is composed of two isotopes, Rb^{85} and Rb^{87} the latter being unstable. Rb^{87} disintegrates to Sr^{87} by the method of beta decay; the same method by which K^{40} decays to Ca^{40} .

In nature, rubidium forms no mineral of its own but rather tends to follow potassium, especially in late magmatic crystallites (Rankama and Sahama, 1950, p. 436). The minerals used for Rb-Sr dating generally have a high potassium content.

The method is complicated by the fact that the strontium occurring naturally contains Sr^{84} , Sr^{86} , Sr^{87} , and Sr^{88} of which Sr^{88} is the most abundant. Ideal minerals for Rb-Sr dating should contain no common strontium and thus all of the Sr^{87} present would be of radiogenic origin. This is rarely the case and it is necessary to make corrections for the common Sr^{87} present in the minerals. The uncertainties that result from the correction of common strontium arise from the uncertainties in the composition of the common strontium. If the common strontium content is small compared with the radiogenic strontium, then the uncertainties have little affect on the value of the radiogenic strontium, but if the reverse is true the determined radiogenic strontium is subject to considerable error (Gast, et al, 1958, p. 325).

Potassium feldspars and micas have been used most for Rb-Sr dating although recently some work has been done on the dating of whole rocks. The dates reported here are all on potassium feldspars from which as much as possible of the perthitic intergrowths of plagioclase has been removed.

The age equation used in calculating the dates can be derived simply from the fundamental radioactive decay rate equation.

$$t \text{ (years)} = 1.56 \times 10^{11} \log ((\text{Sr}^{87}/\text{Rb}^{87}) + 1)$$

The constants used are: (See Goldich et al, 1961, p. 21,24)

$$\lambda = 1.47 \times 10^{-11}/\text{yr}$$

$$\text{Rb}^{87}/\text{Rb} = 27.85 \text{ atomic per cent}$$

Common strontium:

$$\text{Sr}^{87}/\text{Sr}^{88} = 0.0841$$

$$\text{Sr}^{87}/\text{Sr}^{86} = 0.713$$

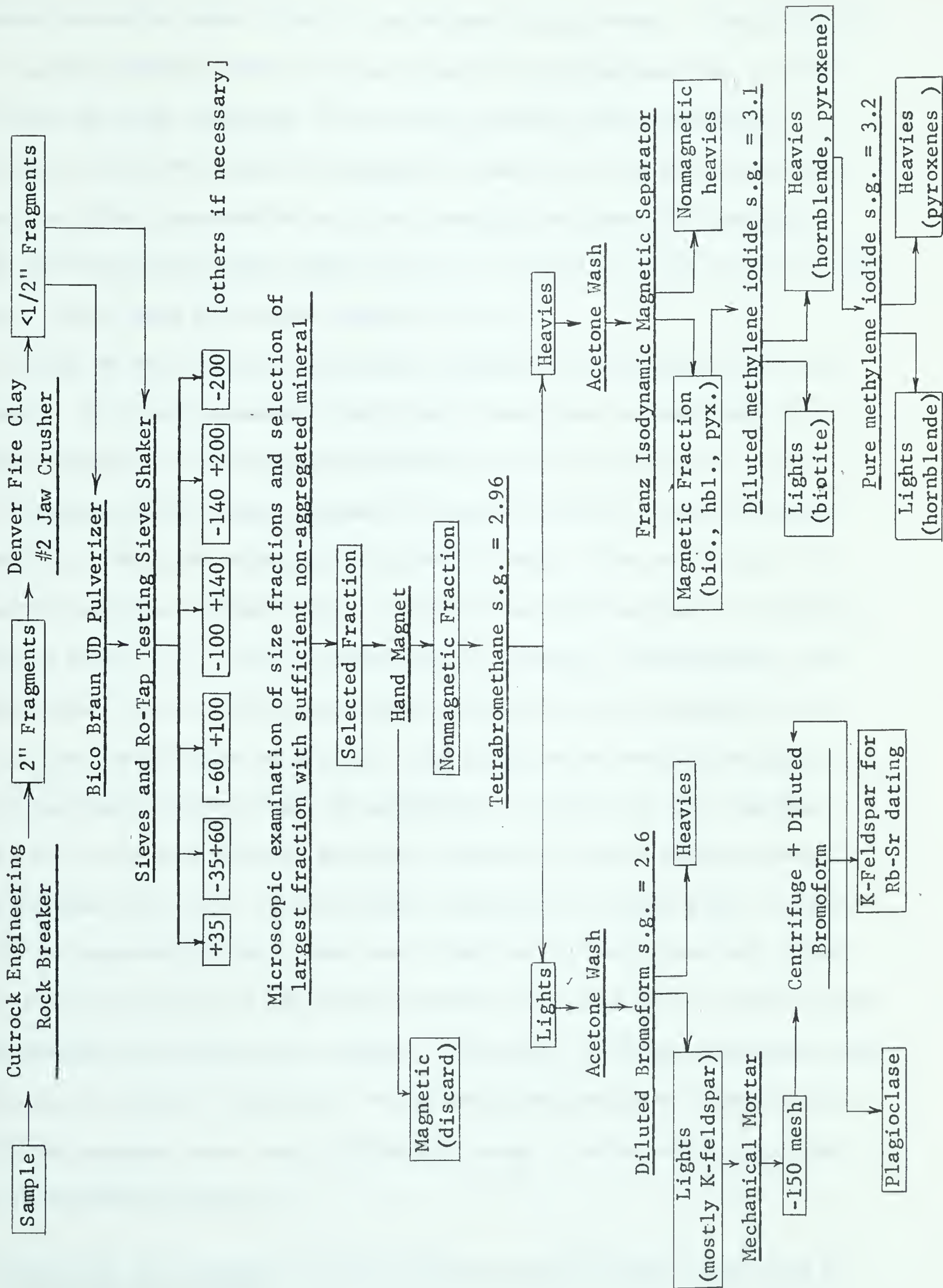
MINERALS DATED AND SEPARATION TECHNIQUES

During the course of the present investigation 45 K-Ar dates were completed. Of this total, 25 were on biotite, 15 on hornblende, 4 on pyroxene, and 1 on muscovite. Biotite was used most because of its almost ubiquitous occurrence in granitic and metamorphic rocks. Potassium feldspars were separated from a few samples and some of these separates were dated by the Rb-Sr method (table 21).

The generalized scheme of separation of biotite, hornblende, pyroxene, and potassium feldspar is shown in figure 16. For the most part this scheme was followed; however, the nature of some samples necessitated modifications in the methods. Some of the problems encountered in the separation of the individual minerals are discussed below.

Biotite.--For most samples in which biotite was the only or main mafic mineral the scheme of separation as shown in figure 16 was followed routinely. In several samples of moderate to coarse grain size a pure biotite separate was obtained by using only the Franz separator after crushing and removing the tramp iron. These separates were washed with acetone to remove adhered rock dust but heavy liquids were not necessary. Pure biotite was obtained from one sample by merely sieving after crushing. The main contaminants in some of the biotite concentrates other than accessory minerals such as zircon, apatite, and sphene which can be removed as non-magnetic fractions on

Figure 16.--Flow sheet showing methods of separation



the Franz Separator, were chlorite, hornblende, and pyroxene. Some chlorite has a specific gravity less than that of pure tetrabromethane and is removed with the light fraction in the initial heavy liquid separation. Separates in which this was not accomplished were purified by repeated runs through the Franz separator at critical amperage and geometric settings. All of the biotite separates dated are free of chlorite. This is well illustrated by their high K_2O values (tables 16-17).

In some of the biotite concentrates pyroxene and hornblende were contaminants. It is not necessary that biotite separates be completely free of these minerals as their K_2O contribution to the total value is quite small, however, every effort was made to remove as much of these minerals as possible. This was accomplished in several ways. The most costly was the use of methylene iodide (s.g. = 3.32) diluted with acetone to a specific gravity of about 3.1. In this mixture biotite floats, and hornblende and pyroxene sink. In addition to methylene iodide two other techniques were used for the purification of biotite. One consisted of rolling the grains down an inclined sheet of paper or cardboard. By virtue of its cleavage, biotite will tend to remain on the paper, whereas the more blocky pyroxene and hornblende roll off. Another method consisted of crushing and sieving. The biotite concentrate was spread very thinly on a steel plate and rolled with a steel rolling pin. The biotite tends to lie flat on the plate whereas the hornblende and pyroxene are crushed. Subsequent sieving concentrates the biotite in the coarser fractions. The magnetic properties of biotite, hornblende, and pyroxene were rarely different enough to allow efficient separations on the Franz separator.

Hornblende and Pyroxene.--Just as these minerals formed impurities in some of the biotite separates, biotite was usually the contaminant in con-

centrates of hornblende and pyroxene. The amount of biotite present is extremely critical because of its high K_2O value compared to that of hornblende and pyroxene. In some of the samples hornblende was the only mafic phase and no problems were encountered in separation.

In most of the hornblende and pyroxene bearing rocks, however, biotite was at least present in accessory amounts and in some, in essential amounts. The same techniques used in removing hornblende and pyroxene from biotite concentrates were used for the initial upgrading of separates of these minerals. The rolling and crushing-sieving methods were not completely satisfactory because they are not as efficient in producing pure hornblende or pyroxene separates as they are in the production of clean biotite separates. However, these methods provided a method of upgrading the sample prior to the sink-float in methylene iodide. An example of this is the hornblende of AK 265. This rock contains considerable biotite but repeated runs through the Franz separator upgraded the hornblende from about 50 per cent to 80 per cent. Repeated rolling on paper further upgraded the separate to 90 per cent hornblende and crushing and sieving produced a purity of 95 per cent. Final sink-float in methylene iodide resulted in a pure hornblende separate in which no biotite was detectable either under the microscope or by the X-ray.

This was the first hornblende separation attempted from a rock containing about equal amounts of biotite and hornblende; several days were required to produce a clean separate. The methylene iodide was used at an earlier stage in the later separations and less time was required to produce a satisfactory sample.

It was impossible to obtain biotite-free hornblende and pyroxene separates from some rocks. This situation was caused by minute inclusions of opaque minerals, probably magnetite, in the biotite and, especially in

basic rocks, in the other minerals. These inclusions increased the specific gravity and magnetic susceptibility of the biotite grains which complicated the separation. By reducing the grain size and removing the more magnetic grains with the Franz separator it was possible to improve the grade of the concentrate.

Pyroxene separates were obtained by using pure methylene iodide in which most amphiboles float and most pyroxenes sink. Magnetite inclusions in hornblende and biotite complicated this separation and pure separates were not obtainable from some samples.

When pure separates were impossible to obtain within practical time limits a cut of the final concentrate was taken with the microsplitter and a grain mount prepared. The purity of the separate was determined by counting on the order of 1000 grains. Impure separates are so indicated in table 19 and this factor must be taken into consideration in the interpretation of the resulting dates.

Muscovite.--Muscovite was separated from only one sample, AK 257. This rock is a medium-grained muscovite granite and no problems were encountered in the separation. The crushed sample was put in diluted bromoform of such density that muscovite sank and the other minerals floated. Apatite and zircon were removed by passing the concentrate through the Franz separator at high amperage.

Potassium Feldspars.--The light fractions obtained during the separation of the other datable minerals were used for the potassium feldspar concentrates. Bromoform diluted with acetone to a specific gravity of about 2.6 was used to float the potassium feldspar and sink quartz, plagioclase, and other minerals. All of the potassium feldspars contained perthitic intergrowths of plagioclase and it was necessary to reduce the grain size to -150 or less mesh size and

centrifuge in diluted bromoform. After the initial separation of the coarse fractions the approximate Sr/Rb ratio was determined by the X-ray fluorescence. This was also done between repeated separations with the centrifuge to determine if progress was being made in removing the plagioclase contaminant, the idea being that more Sr was concentrated in the plagioclase than in the potassium feldspar. When the point was reached that the Sr/Rb ratio remained about the same the separate was assumed to be as clean as possible.

POTASSIUM DETERMINATIONS

The potassium determinations were done in the Geochemistry Laboratory of the University of Alberta by Mr. A. Stelmach. Two methods were used depending on the amount of potassium in the minerals. The high potassium minerals, viz. micas, were analyzed by the gravimetric method using sodium tetraphenol boron ($\text{NaB}(\text{C}_6\text{H}_5)_4$), and the low potassium minerals, viz. hornblende and pyroxene, were analyzed on a Perkin-Elmer flame photometer. A brief discussion of the precision and accuracy of these methods is presented in a later section.

Gravimetric.--Samples of 0.2500 grams are dissolved in H_2SO_4 and HF, and evaporated to dryness and ignited (Abbey and Maxwell, 1960). Successive leaches with water on the residue removes most of the potassium as soluble K_2SO_4 . The remaining insoluble residue is transferred to a filter paper, washed thoroughly, and removed to a platinum crucible where it is again treated with H_2SO_4 , dried and ignited. Subsequent leaches are combined with the first leaches and potassium is precipitated as potassium tetraphenol boron. The precipitate is dried, weighed, and the K_2O content calculated using the appropriate gravimetric factors. The potassium tetraphenol boron precipitate is used in estimating the rubidium correction by X-ray fluorescence.

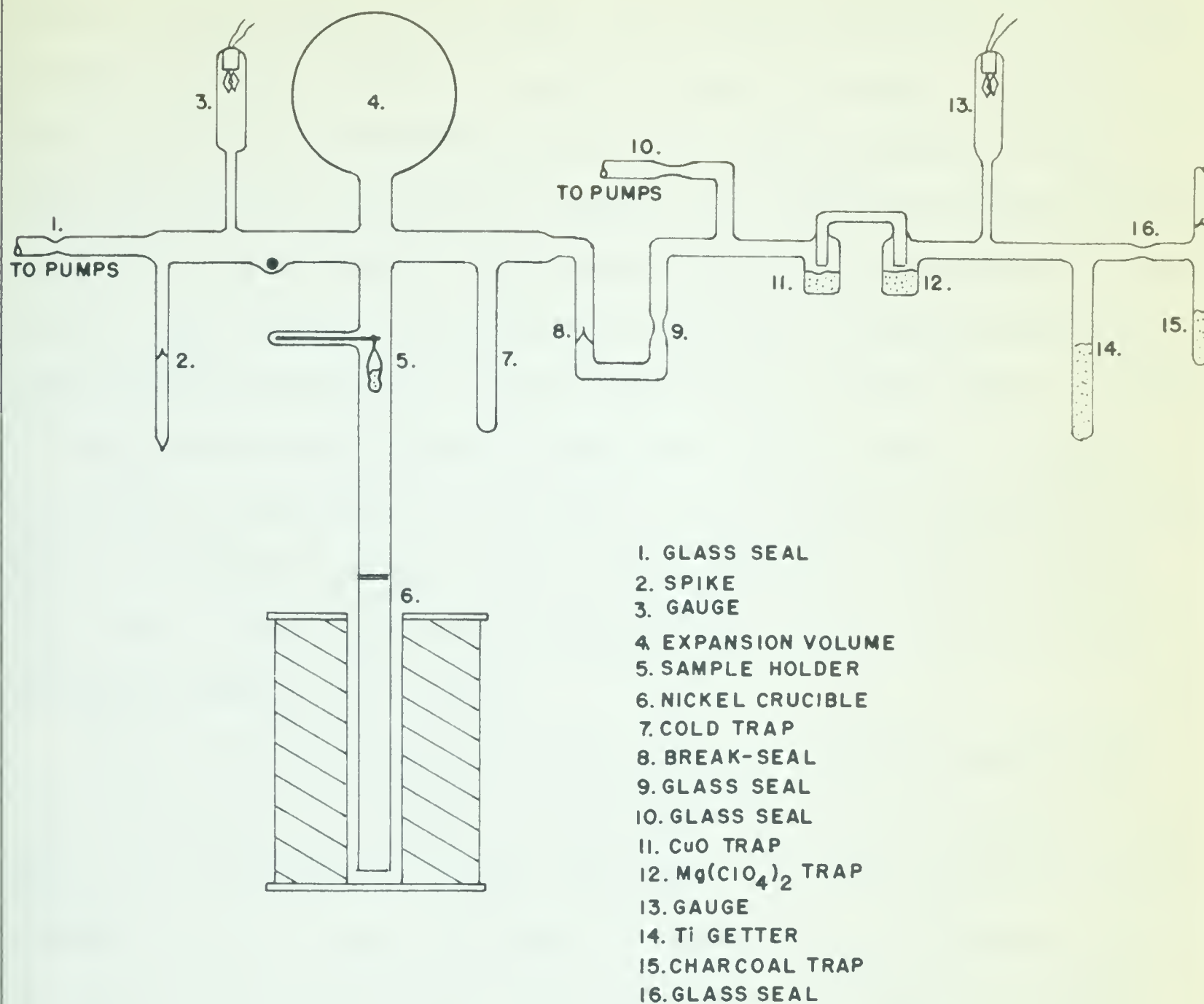
Flame Photometric.--Generally 0.5000 gram samples are used for the potassium analyses of hornblende and pyroxene. For the separates containing biotite impurities, a cut of approximately one-half gram was taken with the microsplitter and this weighed accurately and used for the determination. This latter method was used on impure separates to prevent the possible unmixing or preferential concentration of the biotite impurity during the weighing manipulations. An inhomogeneous distribution of this impurity in a hornblende or pyroxene separate could greatly affect the accuracy of the determination because of the high ratio of potassium in biotite compared to that in hornblende and pyroxene.

After the weighing, the sample is dissolved and leached in the same manner described in the gravimetric method. The resulting solution containing the soluble K_2SO_4 is diluted to 100 ml and the K_2O content is determined on the flame photometer. No rubidium corrections were made on the low potassium minerals.

ARGON DETERMINATION

The determination of the amount of Ar^{40} generated in a mineral by the radioactive decay of K^{40} involves the liberation of the contained argon, and subsequent determination of the amount present. The first phase, the extraction, is a relatively simple matter. The determination of the amount of argon generated is accomplished by adding a known amount of Ar^{38} to the system during the extraction and determining the Ar^{38}/Ar^{40} ratio in the trapped sample.

Extraction.--The technique used in extracting argon from a mineral is essentially the same as that described by Goldich et al (1961, p. 13-16). A diagrammatic sketch of the argon train is shown in figure 17 and reference to this is made in the following brief discussion of procedure.



SCHEMATIC DIAGRAM OF ARGON EXTRACTION TRAIN

Figure 17.--Schematic diagram of argon extraction train.

Depending on the mineral species and its probable age a sample of 1 to 3 grams is used for the fusion. After new seals, spike, and charcoal trap are in place the sample (5) is loaded into the train, approximately 30 grams of NaOH is put into the nickel crucible (6), and the crucible is joined to the train. The flux is heated to about 550° C and the system is allowed to evacuate by pumping for at least 8 hours. When a sufficient vacuum is obtained, the fusion train (f-train) is sealed from the pumps (1), the furnace is cooled, and the sample dropped. The furnace is then turned on and the temperature increased by increments to a maximum of about 650° C and the sample is allowed to fuse at this maximum temperature for about 3 hours. When it is apparent that fusion is proceeding satisfactorily the spike seal is broken with a steel ball manipulated by a magnet, and the Ar³⁸ is allowed to expand throughout the f-train. Water evolved during the fusion is trapped in the cold trap (7) using liquid air as a coolant.

During the fusion the charcoal trap (15) is activated by torching and the titanium getter is torched to expel trapped gases from the previous run. After all visible water is trapped, the furnace is turned off and the melt is allowed to cool, the seal (10) between the pumps and the purification train (p-train) is made, and the seal (8) between the f- and p-trains is broken, initiating the process of purification. As the gases expand into the p-train they pass through the hot CuO trap (11) and any hydrogen that has been generated by the oxidation of Fe⁺⁺ in the mineral is oxidized and the resulting water is trapped in the cooling perchlorate trap (12). When maximum clean-up has been obtained as evidenced by the vacuum gauge, the heater is removed from the charcoal trap (15) and the gases are trapped using liquid air. After about 30 minutes the seal between the F- and P-train is made (9). The charcoal trap is heated and the gases are re-expanded through the p-train. The perchlorate trap (12) is heated again and allowed to remove any water from

the system. After the perchlorate is cooled completely to room temperature, the titanium getter (14) is heated for about 15 minutes and allowed to cool. During the cooling of the titanium getter the argon is trapped onto the charcoal (15) for about 20 minutes and the sample is sealed from the p-train at (16) and removed. The argon sample is then ready for determination with the mass spectrometer. When the run has been completed the furnace is removed and the melt examined in order to determine if all of the mineral has completely reacted. Any unreacted mineral is recovered, weighed, and the original sample weight is corrected.

Isotopic Measurements.--The argon analyses were done by H. Baadsgaard on a 60° Nier-type mass spectrometer located in the Physics Department. The mass spectrometer and general procedure for the determinations are similar to those described by Goldich et al (1961, p. 16-21) and will not be described in detail here. The argon determinations for all of the ages reported were done using the dynamic technique, whereby a continuous flow of argon goes into the mass spectrometer through a molecular leak and is continually pumped away.

The general procedure during a run includes determining the isotopic composition of a sample of air argon. Since the composition of atmospheric argon is well known, this procedure gives a check on the accuracy of the mass spectrometer and allows for correction of any deviations of the measured values as compared to the known composition of air argon. This deviation is referred to as mass discrimination. The ratio of $\text{Ar}^{40}/\text{Ar}^{36}$ as determined by the mass spectrometer is compared with the true value of 295.5 for atmospheric argon. Generally, the ratio of these masses as shown by the strip chart is on the order of 300. Using the difference between the true and measured value a discrimination factor is calculated and this is used in the correction of the measured ratios of $\text{Ar}^{38}/\text{Ar}^{40}$ for the sample argon.

A residual blank is determined prior to each sample run. This is done to determine the amount of material with masses 40, 38, and 36 in the mass spectrometer before letting in the sample argon. In the subsequent calculations, corrections are made for these residual values.

AGE CALCULATIONS

The simplest way to illustrate the calculation of an age from the basic data after completion of the potassium and argon analyses is to present an example. Figures 18 and 19 show a typical strip chart from the mass spectrometer recorder and the calculation sheet for the same run.

In determining the relative values of the isotope peaks from the strip chart the following procedure is used.

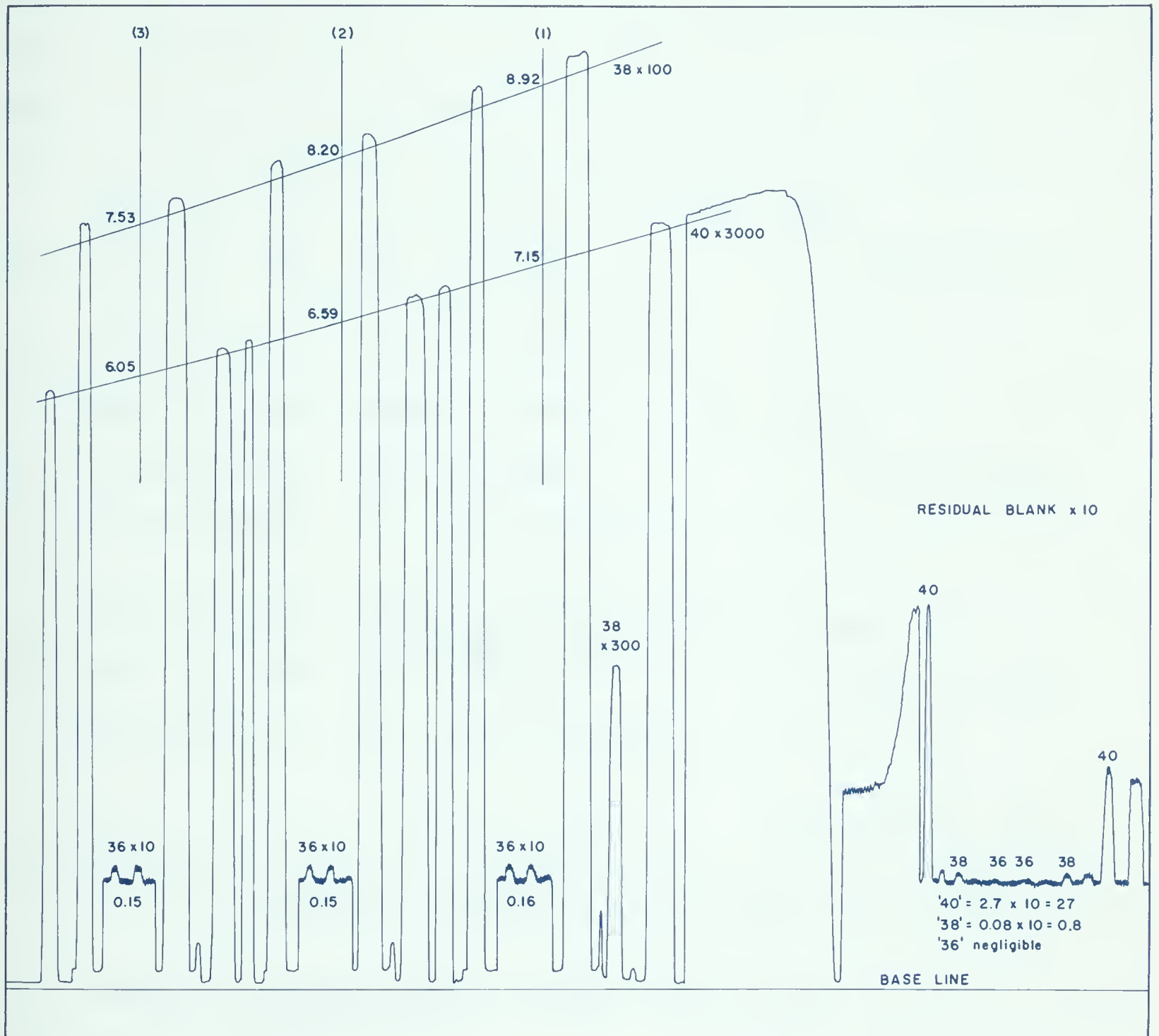
(1) Reduce peaks to common base line, "0" on chart paper, and correct peak heights for this reduction.

(2) Draw smooth curves through corrected peak tops.

(3) Select time lines either between or close to the 36 peaks.

(4) Read and record the relative values of the 40, 38, and 36 masses where the appropriate curves intersect the time lines. Generally for the 36 peaks the two adjacent values are averaged to obtain the value at the time lines.

(5) The residual values are determined from the residual blank portion of the strip chart. The residuals, especially the mass 40 peaks, may increase with time. This increase is important with young samples done statically but rarely has any affect on the results for Precambrian samples with much more radiogenic argon. However, this increase can be corrected for by determining the slope formed by the 40 peaks, or the 38 peaks if they too show increase, and projecting this slope onto the main-run portion of the chart using the end of the pump-down on the last 40 peak of the residual portion of the chart



TYPICAL MASS SPECTROMETER STRIP CHART FOR ARGON

BIOTITE, AK 271, EXTRACTION RUN 306

12 / 19 / 61

Figure 18.--Typical mass spectrometer strip chart for argon.

Figure 19.--Facsimile of calculation sheet for K-Ar age.

Run 306 AK 271

Biotite

Per cent K_2O 7.42

Sample .1.1477 gm

Spike 3.445 cc $Ar^{38} \times 10^{-5}$ STP

$$(40) 7.15 \times 3000 \quad 21,450 - (213 + 27 + 152) = \underline{21058}$$

$$[1] \quad (38) 8.92 \times 100 \quad 892 - 1 = \underline{891} \quad 38/40 = 0.04231$$

$$(36) 0.16 \times 10 \quad 1.6 - 1.1 = \underline{0.5} \quad (304)$$

$$(40) 6.59 \times 3000 \quad 19,770 - (196 + 27 + 152) = \underline{19,395}$$

$$[2] \quad (38) 8.20 \times 100 \quad 820 - 1 = \underline{819} \quad 38/40 = 0.04222$$

$$(36) 0.15 \times 10 \quad 1.5 - 1.0 = 0.5 \quad (304)$$

$$(40) 6.05 \times 3000 \quad 18,150 - (180 + 27 + 182) = \underline{17,761}$$

$$[3] \quad (38) 7.53 \times 100 \quad 753 - 1 = \underline{752} \quad 38/40 = 0.04238$$

$$(36) 0.15 \times 10 \quad 1.5 - 0.9 = 0.6 \quad (304)$$

$$\text{Avg. } 38/40 = 0.04230$$

$$Ar^{38}/Ar^{40} = 0.04230 \times 1.014 = 0.04290 \quad (\text{mass discrimination})$$

$$Ar^{40}/gm = \frac{3.445 \times 10^{-5}}{-1.1477 \times 0.4290} = 0.6998 \times 10^{-3} \text{ cc STP}$$

$$\text{p.p.m. } Ar^{40} = 0.6998 \times 10^{-3} \times 1.7846 \times 10^3 = 1.249$$

$$\text{p.p.m. } K^{40} = 7.42 \times 1.0022 = 7.43$$

$$Ar^{40}/K^{40} = 0.1681$$

$$t = 4.308 \times 10^9 \text{ Log } [1 + (0.1681)(9.08)] = \underline{1.73 \times 10^9 \text{ years}}$$

as the control point (fig. 18). The appropriate 40 residual corrections are then determined at the intersections of the time lines and the residual line.

When interpretation of the chart is complete the relative isotope values at the three time lines are transferred to the calculation sheet and multiplied by the appropriate scale factors. These sets of readings are shown as (1), (2), and (3) in figure 19.

In order to make the corrections it is necessary to know the source of the various argon isotopes recorded on the strip chart. The argon sample obtained from the extraction contains argon from the mineral, the spike, and any air which may have been present in the train during the run.

It is necessary to determine the ratio of Ar^{38} from the spike only to Ar^{40} from the mineral only. Therefore, it is necessary to remove the contributions of the other sources of these isotopes from the total values determined from the chart. These corrections are made as follows.

$$\text{Ar}_{\text{radiogenic}}^{40} = \text{Ar}_{\text{total}}^{40} - (\text{Ar}_{\text{spike}}^{40} + \text{Ar}_{\text{air}}^{40} + \text{Ar}_{\text{residual}}^{40})$$

$$\text{Ar}_{\text{spike}}^{38} = \text{Ar}_{\text{total}}^{38} - (\text{Ar}_{\text{air}}^{38} + \text{Ar}_{\text{residual}}^{38})$$

$$\text{Ar}_{\text{air}}^{36} = \text{Ar}_{\text{total}}^{36} - (\text{Ar}_{\text{residual}}^{36} + \text{Ar}_{\text{spike}}^{36})$$

In practice the Ar^{38} correction from the air is ignored because it is negligible; air argon contains only 0.063 atomic per cent Ar^{38} . The residual corrections are the values obtained directly from the strip chart. The Ar^{38} from the spike is obtained then by subtracting the residual from the total Ar^{38} . The composition of the spike argon is determined accurately during preparation of the spike sets, and the contribution of spike argon to the total Ar^{40} and Ar^{36} can be determined as follows:

$$\text{Ar}_{\text{spike}}^{40} = \text{Ar}_{\text{spike}}^{38} \times (\text{Ar}^{40}/\text{Ar}^{38})_{\text{spike}}$$

$$\text{Ar}_{\text{spike}}^{36} = \text{Ar}_{\text{spike}}^{38} \times (\text{Ar}^{36}/\text{Ar}^{38})_{\text{spike}}$$

At this point the amount of Ar^{36} contributed by air contamination has been determined and the remaining correction is the Ar^{40} contribution from the air argon. Rather than use the known $\text{Ar}^{40}/\text{Ar}^{36}$ value for air which is 295.5 the value determined by the mass spectrometer during the tank argon run is used. For this example the value is 304 and the correction is calculated as follows:

$$\text{Ar}_{\text{air}}^{40} = \text{Ar}_{\text{air}}^{36} \times (\text{Ar}^{40}/\text{Ar}^{36})_{\text{air}} = \text{Ar}_{\text{air}}^{36} \times 304$$

After these final corrections are made the $\text{Ar}^{38}/\text{Ar}^{40}$ ratio is calculated for each set of figures and an average value obtained. A correction for mass discrimination is then made; the factor for this example is 1.014. This factor multiplied by the apparent $\text{Ar}^{38}/\text{Ar}^{40}$ ratio gives the true value. Using this it is a simple matter to determine the amount of radiogenic argon evolved from the mineral during extraction. The volume of Ar^{38} introduced into the extraction train is known by the spike value previously determined. The true ratio of $\text{Ar}^{38}/\text{Ar}^{40}$ in the sample argon has been determined and the weight of sample used in the fusion is known. The volume of Ar^{40} is calculated as follows (fig. 19):

$$\text{Ar}^{40} \text{ cc STP/gm} = \frac{\text{cc STP Ar}^{38}}{\text{gms sample} \times \text{Ar}^{38}/\text{Ar}^{40}}$$

The volume of Ar^{40} is converted to parts per million by the factor shown. The parts per million of K^{40} are calculated in similar manner from the per cent K_2O in the mineral. The $\text{Ar}^{40}/\text{K}^{40}$ ratio and the age of the mineral are calculated as shown in the example (fig. 19).

Evaluation of Methods and Minerals

The accuracy of the K-Ar and Rb-Sr methods depends on how well the basic requirements outlined on page 161 are met. For individual dates some of these requirements are difficult to evaluate. Many of the possible factors which affect the accuracy of the methods are geologic in nature and may be evidenced in the rocks, for example dynamic metamorphism as indicated by shearing, or weathering or retrograde metamorphism as suggested by chemical alteration. The effects of such processes must be looked for in the rocks in order that the dates may be reasonably interpreted.

Other main factors influencing the accuracy of the determinations are the analytical techniques and their precision. The decay constants may be considered in this category because without reliable data on the rate of radioactive decay the resulting dates will be in error in an absolute sense. As more reliable decay constants are determined in the laboratory, or geologically, the accumulated data can be recalculated but the relative differences in ages will remain the same. Of more importance in a relative sense are the analytical determinations of the parent and daughter products for a particular decay scheme.

In the following section a brief discussion of analytical and geological factors affecting the accuracy and precision of the K-Ar and Rb-Sr determinations is presented. All the possible sources of error are not mentioned as almost every manipulation involved in the determination may have certain possible inherent errors.

K-Ar METHOD

Analytical Precision.--Any evaluation of accuracy is difficult because it is necessary to know the absolute value of the quantity in question. The precision or the degree of reproducibility is more easily evaluated and the

accuracy can not be better than the precision although precise determinations do not necessarily imply accuracy.

One of the major analytical uncertainties in the K-Ar method is the determination of potassium. Pinson (1961, p. 221) notes that it is indeed peculiar that argon which occurs in only trace amounts in minerals can be analyzed with more certainty than the major element potassium. The difficulty in potassium analyses is well exemplified by replicate determinations on the MIT standard biotite (Hurley et al, 1961, p. 276). Fourteen values reported by 12 different laboratories vary from 7.40 to 7.80 per cent K and the average is 7.58 per cent. The value obtained at the Alberta Rock Analysis Laboratory is 7.46 per cent by the gravimetric method (Baadsgaard, personal communication). Assuming that the cuts obtained by the various laboratories were equivalent in potassium content, the differences reported are due to different methods and techniques although values obtained by the same method at different laboratories do not necessarily agree. The true value of the potassium content is not known but the range reported, in the order of 6 per cent, indicates the poor degree of precision attained by interlaboratory determinations. Generally, replicate analyses by a single laboratory agree much better than the potassium values reported for the MIT biotite.

Goldich et al (1961, p. 11) report that the precision obtained at the Minnesota Rock Analysis Laboratory over a number of years was generally within one per cent of the potassium content for values in the range of 1 to 14 per cent K_2O . Several replicate determinations on the same samples have been completed by A. Stelmach using the method described previously and the results are in good agreement. Examples of these replicate determinations are four analyses of a biotite sample which gave an average value of 7.75 per cent K_2O with a mean deviation from the average of 0.02 and a range of 7.72 to

7.78. Four analyses of feldspar gave an average of 14.01 per cent K_2O with a mean deviation of 0.01 and a range of 14.00 to 14.03. These examples give an idea of the probable precision for the values of biotite reported here because they were done by the same method and analyst.

No replicate determinations have been made on hornblende or pyroxene at this laboratory but Hart (1961a, p. 2996) reports a precision of about two and one-half per cent for potassium determinations on these minerals with the flame photometer. A similar precision is expected for the determinations reported here for values of one-half per cent potassium or greater. Even though half gram samples were used, the reproducibility of samples containing less than one-half per cent potassium is greatly affected by the pure mechanics of reading the flame photometer. It is only possible to estimate the flame photometer reading to about $\pm .0005$ ppm K_2O . This possible deviation results in about 0.01 per cent K_2O error. In other words a pyroxene containing 0.05 per cent K_2O would have to be reported as containing $0.05 \pm .01$ per cent K_2O . This results in a range of 40 per cent and must be taken into account in the presentation of the calculated age. The deviation caused by the sensitivity of the flame photometer could be partially eliminated by taking larger cuts for the potassium analyses. Most of the amphiboles analysed contained more than one-half per cent potassium and the determinations should be reliable. Two pyroxenes contained only 0.04 per cent K_2O but the determinations would have to be off by a factor of 10 before the anomalous ages of these pyroxenes could be explained by errors in the potassium analyses. One pyroxene contains 0.11 per cent potassium and the probable error is about 10 per cent. Two low-potassium hornblendes contained only 0.28 and 0.35 per cent K_2O and the uncertainties for these would be 3 per cent. The uncertainties in the potassium determinations are transferred directly to the Ar^{40}/K^{40} ratios but are reduced somewhat in magnitude by the logarithmic function of the age formula.

Other factors not considered, a pyroxene 1.75 b.y. old would have an uncertainty in the age of 6 per cent if the K_2O content were $0.10 \pm .01$ per cent. Thus a 10 per cent uncertainty in the potassium content is reduced to 6 per cent in the final age calculation.

Argon analyses can generally be done with better reproducibility than the potassium analyses both by an individual laboratory and interlaboratory determinations. The accuracy and reproducibility of the argon analyses depends to a great extent on the accuracy of the spike calibrations and the final isotopic measurements on the sample and spike argon mixture. Other factors stem from the extraction techniques. These may include incomplete fusion of samples, air contamination, isotopic fractionation of argon, and many other factors difficult to evaluate without replicate analyses (Goldich, et al, 1961, p. 21).

A fair degree of reproducibility of argon analyses is shown by the interlaboratory determinations on the MIT biotite (Hurley, et al, 1961, p. 277). The nine values reported range from 3.81 to 3.95×10^{-4} cc Ar^{40} STP and the average is 3.88×10^{-4} . The value obtained by Baadsgaard (personal communication) on a routine run is 3.86×10^{-4} . The maximum range reported is about 3 per cent which is considerably better than for the potassium determinations. Most individual laboratories consider their precision in argon analysis somewhat better than 3 per cent.

The probable error in the Ar^{40}/K^{40} ratio is dependent directly on both the accuracy of the Ar and K analyses and thus individual laboratories are able to reproduce these ratios better than that indicated by the interlaboratory checks. Baadsgaard, et al (1957, p. 541) indicated a precision of about 5 per cent for Ar^{40}/K^{40} ratios determined on the same samples at different laboratories. Goldich, et al (1961, p. 21) have made replicate determinations for argon on 90 samples. The average difference in Ar^{40}/K^{40} ratios for these

is 3.5 per cent. The determinations on 54 of the samples showed the following deviations.

- (1) 43 samples differed by less than 5 per cent
- (2) 27 samples differed by less than 3 per cent
- (3) 9 samples differed from 5 to 10 per cent
- (4) 2 samples differed by more than 10 per cent

This study gives an idea of what can be predicted about an individual determination with no replicate analyses. The odds are in favor of any single determination being reproducible to within 5 per cent and the chances are even that it can be reproduced within 3 per cent. Unfortunately when a number of determinations are done on different samples, eventually there will be one or more in which some or all of the possible errors in the method will be additive in either a positive or negative sense and the result will be considerably in error.

For the ages reported here, the maximum probable error for the A^{40}/K^{40} ratio is assumed to be 5 per cent. For Lower Proterozoic and Archean rocks this results in about 3 per cent error in the age reported. The dates on the low potassium hornblende and pyroxene samples may be in excess of this 3 per cent error. It should be mentioned again that these probable errors are analytical in nature. Some of the geological uncertainties are discussed in the following section.

Geological Factors.--The major uncertainty in the K-Ar method other than analytical problems is the possible loss of argon from the mineral system as the result of either continuous diffusion or some geologic event occurring over a definite time interval. Low temperature potassium feldspar was initially much used for the K-Ar method because of its high K_2O content and common occurrence. It has since been proven that argon is not completely

retained by the lattice and apparently leaks in a continuous manner. The ages determined on low-temperature potassium feldspars are generally about 35 per cent lower than ages for co-existing micas. The graphs of Goldich et al (1957, p. 548, 549) illustrate this point. The high-temperature potassium feldspar, sanidine, appears to retain radiogenic argon and has proven useful in dating Phanerozoic bentonite beds which form time-rock horizons in the stratigraphic section (Folinsbee, et al, 1960; Baadsgaard, et al, 1961).

Since biotite has been used most commonly for K-Ar dating the problem and possibility of argon loss is very critical. There are many examples in the literature of concordant K-Ar biotite dates and dates obtained on other minerals by different methods as well as Rb-Sr biotite dates. An example of this rather good agreement are the results obtained at Minnesota (Goldich et al, 1961, p. 27). The fact that such agreement exists suggests strongly that biotite under most static conditions does retain argon. Any geologic event which causes recrystallization of biotite will most likely expel the generated argon and thus reset the "biotite clock." Unfortunately, it is not known under what minimum conditions this will take place.

Other examples show biotite ages which are considerably lower than those obtained on co-existing minerals by other methods. Goldich et al (1957, p. 549) present data showing the greater instability of biotite compared with feldspar with regard to argon loss as a result of a finite geologic event. Where gabbro has intruded older rocks, the K-Ar biotite ages have been reduced considerably more than the K-Ar feldspar dates even though feldspar continuously diffuses argon. Dates obtained from the Baltimore gneiss (Tilton et al, 1958) and the Finnish shield (Wetherill et al, 1962) also indicate a greater instability of biotite. Ages of about 300 m.y. are obtained from biotite in the Baltimore gneiss whereas Rb-Sr dates on feldspar indicate an age of 1100 m.y. for the rock. This older date is substantiated by U-Pb

determinations on zircon. A similar situation occurs in Finland (Wetherill et al, 1962) where biotite dates by the K-Ar method and most dates by the Rb-Sr method indicate an age of about 1800 m.y. Rb-Sr dates on muscovite and feldspar and U-Pb dates on zircon indicate a true age of about 2700 m.y. The younger dates in both examples are related to later metamorphic events, and because the biotite is more susceptible to alteration by these events, lower K-Ar ages are obtained. In these two examples where it has been possible to use other methods in addition to K-Ar, the argon loss from the biotite has been a useful feature. The U-Pb zircon dates and the Rb-Sr feldspar dates indicate the original age of the rocks and the K-Ar biotite dates show the effect of the much later period of metamorphism.

A recent study of argon diffusion from biotite has been completed on a suite of samples from New Zealand (Hurley et al, 1961, p. 7-26). A late Tertiary or early Quaternary fault has caused uplift, and subsequent erosion has exposed Mesozoic metamorphic rocks of moderate to low grade. Calculated depths indicate a burial of about 9000 feet prior to the uplift. Micas dated by the K-Ar method from these rocks show anomalously low ages and this is interpreted to mean that argon was not retained at the conditions prevailing in the rocks prior to uplift. Using assumed geothermal gradients Hurley, et al (1961, p. 20) have concluded that the biotites . . . "have lost essentially all their argon at a temperature of 100° C or conceivably on cooling from 100° C." This minimum can not be taken as a minimum temperature for argon loss in all biotites because as the authors point out, the area has been one of considerable deformation and thus factors other than temperature are involved.

The fact that a threshold temperature of around 100° C alone cannot cause argon loss is shown by the present study where many of the samples have been at considerable depth for some time. An example is the Shell N.P. well in Montana. Depth to the samples is 11,050 feet. Using an average gradient

given by Levorson (1956, p. 401) of 1.11° C/ft, the calculated bottom hole temperature is 133° C assuming a mean annual surface temperature of 10° C. Co-existing biotite and hornblende were dated with results of 1.72 and 1.77 b.y. respectively (table 16). The difference in dates is within the possible analytical error and cannot be attributed to argon loss from biotite because of an environmental temperature in excess of 100° C. Perhaps if dynamic metamorphism had affected these basement rocks at approximately the calculated temperature, argon would have escaped. The relations mentioned above indicate that the threshold conditions under which biotite will begin to lose argon are not completely known. In one instance a temperature of 100° C accompanied by directed stress is sufficient to cause outgasing but the other example given indicates a retention of argon even though the 1.7 b.y. old biotite was in an environment in which the temperature exceeded 100° C for considerable time.

Recently it has been shown that hornblende may retain argon better under higher temperature conditions than does biotite (Hart, 1961b, p. 194). The present study and other investigations carried out at the University of Alberta seem to confirm this possibility (Hunt, 1961; Burwash, et al, 1962).

Pyroxenes dated during the present study indicate complications which have not been resolved. Of the five pyroxene samples dated, two are hypersthene which give geologically reasonable dates. The remaining three are on clinopyroxenes and the dates are completely anomalous and can be explained only by occlusion of argon or loss of potassium.

Neither the present study nor the investigation of Hart (1961a) show indications of inherited or occluded argon in amphiboles as originally thought (Damon and Kulp, 1958). Presence of "excess" argon in biotites is doubtful because of the many examples of K-Ar dates in agreement with those obtained by other methods. Biotite dates from areas that have undergone more than one thermal event may indicate "excess" argon if survival values are ob-

tained but it is "excess" only in terms of the final event and represents incomplete outgasing of the sample. Some examples are given by the present investigation (AK 213, table 17; AK 166, table 16).

Loss of potassium from the system without the loss of argon is a situation which would result in dates older than the true age. Such a process may occur for pyroxenes as mentioned above but there is no evidence that such a process was operative on biotite and hornblende. Kulp and Basset (1961, p. 225-226) have done leaching experiments on biotite but the results indicate a decrease in the $\text{Ar}^{40}/\text{K}^{40}$ ratios and they conclude that the K-Ar method should always give minimum dates. The process of chloritization of biotite results in the loss of potassium from the lattice and apparently also loss of argon. Preliminary studies of the Geological Survey of Canada (Lowdon, 1961, p. 123) suggest that partial chloritization of biotite has little effect on the $\text{Ar}^{40}/\text{K}^{40}$ ratio.

Rb-Sr METHOD

Analytical Precision.--The interlaboratory precision for this method is shown by the results obtained on the MIT standard biotite (Hurley et al, 1961, p. 275). Nine laboratories have reported rubidium contents ranging from 425 to 466 p.p.m. and strontium values from 10.0 to 12.2 p.p.m. The total ranges are about 10 per cent for rubidium and 20 per cent for strontium. Radiogenic Sr^{87} determinations from 1.69 to 1.77 p.p.m. are reported by six laboratories and the range is about 5 per cent.

Goldich et al (1961, p. 25) consider $\text{Sr}^{87}/\text{Rb}^{87}$ ratios reproducible to within ± 5 per cent; duplicate determinations on nine samples gave a maximum difference of 6 per cent and a mean difference of 2.5 per cent.

Geologic Factors.--Many of the geological uncertainties for the K-Ar method also apply to the Rb-Sr method. With regard to a single mineral species such as biotite, it is known that under certain geologic conditions radiogenic strontium will be expelled from the system, in some known instances more readily than argon. Age results on the Finnish shield mentioned previously (Wetherill et al, 1962) exemplify the loss of strontium by later metamorphism. Recently it has been suggested that a whole rock may act as a closed system under metamorphic conditions and although strontium may be redistributed among the various mineral phases, the total rubidium-strontium content may not be affected. This possible redistribution of strontium presents one of the major uncertainties in the method--that of correction for normal strontium. In some minerals the normal or common strontium content may be very low compared to the content of radiogenic strontium and the uncertainties involved in correcting for the common strontium are small (Gast et al, 1958). With increased common strontium content the uncertainties resulting from the possible variation in the composition of common strontium become much greater and may result in considerable error for the calculated age. Many analyses on various rocks indicate that the normal strontium content is fairly constant (Gast, 1961, p. 182). However, in a system where redistribution of strontium has occurred, corrections based on the average composition of normal strontium could cause considerable error in the individual mineral dates.

Assume for example, a granite which crystallized at a certain time and contained some common strontium. As the Rb^{87} in the various mineral phases decays, the amount of Sr^{87} increases. At some later date, the rock is subjected to metamorphism causing redistribution of the accumulated radiogenic strontium among the various mineral phases. If ages are determined on the individual mineral species and the average composition for common strontium used in the corrections, the dates may neither represent the primary age of

the granite nor the time of subsequent metamorphism. When the radiogenic Sr^{87} is redistributed among the phases it becomes, with regard to the time of metamorphism, common strontium. This type of situation is described in more detail by Compston and Jeffery (1961), Hart (1961b), and in various papers in Hurley, et al (1961).

A situation of the type described above does not render the Rb-Sr method useless but actually allows a more thorough study of a rock system and its geologic history than was hitherto possible. In order to investigate such a system it is necessary to analyze the whole rock and various individual phases. The results are evaluated graphically. Intersections of development curves for $\text{Sr}^{87}/\text{Sr}^{86}$ versus time for the various mineral phases and whole rock would indicate the time of homogenization or metamorphism (Hart, 1961b, p. 193). Analyses of rubidium-free strontium-bearing phases which should normally give the average composition assumed for common strontium, would indicate a higher Sr^{87} content. Some of the Massachusetts granites reported in Hurley, et al (1961, p. 249-254) may have undergone homogenization during a later period of metamorphism. Whole rock dates indicate an age of about 480 to 490 m.y. Intersections of biotite, potassium feldspar, and whole rock $\text{Sr}^{87}/\text{Sr}^{86}$ development curves suggest the later event occurring at 315 to 355 m.y. ago.

Thus, in the interpretation of individual mineral Rb-Sr dates it is necessary to consider firstly, the amount of common strontium present and secondly, the possible variation in ages which could be caused by uncertainties in the normal strontium composition if the amount is great compared to radiogenic strontium. Rocks suspected of having complex geologic histories may have anomalous normal strontium and the dates obtained could be considerably in error. Junctions of age provinces would be suitable places for such situations to occur because of the possibility of "older" rocks being affected by the younger orogenic effects.

Dating Results

In the following section the results of the radioactive dating aspect of this study are presented. All of the dates are given in tables 16 and 17, depending on whether the samples are from the basement or outcrop areas respectively. A summary of pyroxene dates, comparisons of dates on co-existing biotite and hornblende, and dates from impure hornblende and pyroxene separates are given in additional tables. Regional interpretations are presented in a later section.

BASEMENT SAMPLES

Dates obtained on basement samples are tabulated (table 16) with the pertinent analytical data. The mineral dated is indicated but reference should be made to the petrographic section and appendix for descriptions of the dated rocks; locations and other well data are given in table 1.

OUTCROP SAMPLES

Dates of outcrop samples are given in table 17 as well as data on rock types, precise and general locations, geologic ages, and references to the pages of this thesis where the outcrop samples are discussed in light of local geology. Complete sample descriptions are presented in the appendix.

DATES OF CO-EXISTING BIOTITE AND HORNBLLENDE

Five sets of dates obtained on co-existing, and apparently coeval, hornblende and biotite are given in table 18. Samples KA 151 and AK 273; AK 173 and AK 275; AK 176 and AK 265 are from the same specimens. Samples AK 36 and AK 274 are from the same core but different rock types, and AK 177 and AK 167 are from the same outcrop but different rock types. The rather

Table 16.--K-Ar analytical data and dates for basement samples

Index No.	AK No.	Sample No.	Mineral Dated	K ⁴⁰ p.p.m.	Ar ⁴⁰ p.p.m.	$\frac{\text{Ar}^{40}}{\text{K}^{40}}$	Date (b.y.)	Ar ⁴⁰ * (%)
1	172	4222	Biotite	8.61	1.443	0.168	1.73	99.9
4	281	2428	Hypersthene	0.11	0.0219	0.198	1.92	57.2
5	KA 151	2430	Biotite	5.25	0.8461	0.161	1.68	92.4
5	273	"	Hornblende	1.86	0.3014	0.162	1.69	98.2
7	276	4225b	Hornblende	0.96	0.1632	0.170	1.75	96.4
10	175	4224	Biotite	7.54	1.172	0.155	1.64	99.6
13	195	4485c	Biotite	7.79	1.321	0.170	1.75	99.7
14	178	4215	Biotite	8.84	1.352	0.153	1.63	99.6
18	259	4677	Biotite	8.43	1.383	0.164	1.71	99.5
22	173	4231d	Biotite	7.29	1.277	0.175	1.78	99.2
22	275	"	Hornblende	0.62	0.1038	0.167	1.73	96.4
27	264	3633	Biotite	7.47	0.7380	0.0987	1.20	98.1
28	284	3634	Hornblende	1.66	0.2223	0.134	1.49	96.6
30	171	4219	Biotite	6.76	1.115	0.165	1.71	98.2
31	212	4483	Biotite	9.04	1.310	0.145	1.57	98.8
32	168	4234	Biotite	7.89	1.080	0.137	1.51	99.9+
34	166	4216	Biotite	7.79	1.543	0.198	1.93	99.5
36	170	4235	Biotite	8.30	2.552	0.308	2.49	99.3
35	169	4233	Biotite	8.54	2.499	0.293	2.43	99.5
37	AK 36	3798	Biotite	7.92	1.315	0.166	1.72	99.1
37	274	"	Hornblende	0.87	0.1504	0.173	1.77	97.3
39	266	4678	Hypersthene	0.59	0.1455	0.246	2.20	95.3
40	253	4682	Biotite	9.35	2.759	0.295	2.44	99.1
42	254	4681	Biotite	9.01	2.770	0.307	2.49	99.6

* per cent radiogenic argon

Table 17.--K-Ar analytical data and dates for outcrop samples

Index No.	AK No.	Sample No.	Mineral Dated	K40 p.p.m.	Ar ⁴⁰ p.p.m.	$\frac{\text{Ar}^{40}}{\text{K}^{40}}$	Date (b.y.)	Ar ⁴⁰ ** (%)
43	277	RB396 2-61	Hornblende	0.82	0.2422	0.295	2.44	99.0
44*	KA160	1103	Muscovite	10.01	1.695	0.169	1.74	99.9+
45	[	174	Biotite	8.35	1.384	0.166	1.72	98.5
		215	Pyroxene	0.04	0.1317	3.3	6.4	97.6
		216	"	0.79	0.2186	0.276	2.35	99.2
46*	263	3000	Hornblende	0.88	0.0901	0.102	1.23	94.5
47	[	269	4683 Hornblende	0.45	0.0814	0.181	1.82	95.4
		271	4683 Biotite	7.42	1.249	0.168	1.73	99.4
		272	4683 Hornblende	0.28	0.0473	0.169	1.74	89.2
			Au23-5					
48	[	255	4500 Hornblende	0.66	0.1116	0.169	1.74	99.0
		257	4500 Muscovite	10.43	1.765	0.169	1.74	99.8
49	[	256	4500 Hornblende	1.77	0.5134	0.290	2.41	99.0
		192	4500 Biotite	8.69	1.442	0.166	1.72	99.6
50	258	4500 Pyroxenes	0.04	0.0209	0.521	3.27	72.0	
51	[	206	4499A Biotite	9.16	2.829	0.309	2.50	99.7
		207	4499B Biotite	9.15	1.690	0.185	1.84	99.3
		213	4499C Biotite	8.22	1.845	0.225	2.08	99.6
52	[	205	4498A Biotite	8.75	2.478	0.283	2.38	99.7
		208	4498B Biotite	9.01	3.032	0.336	2.62	99.3
53	[	176	4685-10 Biotite	9.01	1.540	0.171	1.75	99.7
		265	" Hornblende	0.77	0.1364	0.177	1.79	97.0
54	[	167	4684-7 Hornblende	1.11	0.1829	0.165	1.71	99.0
		177	4684-6 Biotite	8.15	1.383	0.170	1.74	99.1

* Burwash et al (1962)

** Per cent radiogenic argon

Table 17.--Additional data for outcrop samples. (cont'd)

Index No.	Rock Type	Lat. (N)	Long. (W)	General Area	Geologic Age	Page
43	Hbl. hornfels(?)	59°59'	109°35'	Tazin Lake, Sask.	pre-Tazin(?)	33
44	Qtz-fd. pegmatite	59°45'	106°25'	Stony Rapids, Sask.	post-Tazin	31
45	Porph. bio. granite	59°21'	105°41'	"	post-Tazin	31
	Pyx.-hbl. granulite	59°29'	105°36'	"	pre-Tazin	33
	"	"	"	"	"	"
46	Uralitic diabase	57°26'	106°54'	Cree Lake, Sask.	post-Athabasca	35
47	Bio.-hbl. qtz. diorite	56°44'	101°12'	Lynn Lake, Man.	pre-Sickle	61
	Bio. qtz. diorite	"	"	"	pre-Sickle	62
	Amphibolite	56°43'	101°12'	"	Wasekwan	64
48	Hbl. diorite	56°38'	99°36'	Rusty Lake, Man.	pre-Sickle(?)	61
	Musc. qtz monzonite	56°43'	99°34'	"	post-Sickle	61
49	Hbl. qtz. diorite	54°47'	101°50'	Flin Flon, Man.	pre-Missi	61
50	Pyx.-hbl. gneiss	55°19'	97°40'	Thicket Portage, Man.	pre-Assean Lake group	73
	Bio. gneiss	55°19'	97°40'	"	"	73
	Diabase	55°19'	97°40'	"	post-Assean Lake group	
51	Bio. gneiss	54°38'	97°47'	Cross Lake, Man.	pre-Cross L.	83,85
	Bio. granodiorite	54°36'	97°56'	"	"	83,85
	Qtz. diorite	54°35'	97°45'	"	post-Cross L.	83,85
52	Bio. gneiss	54°32'	94°30'	Gods Lake, Man.	pre-Oxford	85
	Hbl-bio granodiorite	54°38'	94°30'	"	post-Oxford	85
53	Bio.-hbl. gneiss	47°01'	110°46'	Little Belt Mtns., Montana	pre-Beltian	99
	"	47°01'	110°46'	"	"	99
54	Amphibolite	47°55'	108°34'	Little Rocky Mtns., Montana	pre-Beltian	96
	Bio. schist	47°55'	108°34'	"	"	96

* Pages where discussed

good agreement obtained on the two minerals is encouraging. The differences between dates obtained appear to be random with regard to sign and probably represent analytical inaccuracies. The mean absolute difference is 0.04 b.y. which is well within the possible analytical error for samples of this age. Two of the hornblende separates contain biotite as a contaminant, however, correction for the biotite impurity causes little change in the dates reported (table 19).

The results of the duplicate dates obtained on co-existing biotite and hornblende are interpreted as indicating that both biotite and hornblende were formed or recrystallized at approximately the same time, and the hornblende neither inherited nor occluded argon which may have been present in the system at that time. This last interpretation is in accord with Hart's (1961a and b) findings.

Table 18.--Comparison of K-Ar dates on co-existing biotite and hornblende.

Index No.	Biotite (1)		(2) Hornblende		(1)-(2)
	AK No.	Date (b.y.)	Date (b.y.)	AK No.	
5	KA151	1.68	1.69 (2.8 bio.)	273	-.01
22	173	1.78	1.73 (1.2 bio.)	275	+.05
37	36	1.72	1.77 (pure)	274	-.05
53	176	1.75	1.79 (pure)	265	-.04
54	177	1.75	1.71 (pure)	167	+.04
Mean		1.74	1.74		[.04]

DATES ON IMPURE HORNBLLENDE AND PYROXENE SEPARATES

Data for impure hornblende and pyroxene separates are shown in table 19. An estimate of the per cent potassium-bearing impurity, usually biotite, is tabulated and the contribution of the impurity to the total potassium value

is calculated. This contribution is based on known or assumed potassium contents for the impurities. Where the actual value is not known an assumed content of 8 per cent K_2O is used for biotite. As mentioned in table 19 the per cent biotite impurity given is undoubtedly a maximum value because it represents a percentage based on the number of grains present. For example, in a separate of certain mesh size the hornblende grains will be of larger volume than the biotite grains because of the shape of the cleavage fragments. On this basis alone the percentage indicated could probably be safely reduced by one-third. Another reduction could be obtained by converting grain per cent to weight per cent since biotite is lighter than hornblende. In order to do this accurately the average grain size of both the biotite and hornblende would have to be determined. Another method was attempted but found unreliable. This consisted of preparing known mixtures of biotite and hornblende and attempting to set up standard curves based on X-ray peak heights for two strong reflections of biotite and hornblende. So many uncertainties were inherent in both the preparation of the mounts and lack of reproducibility by repeated scannings that the method was abandoned in favor of the time-proven microscope.

As can be seen in table 19 most of the potassium contributions from biotite are less than 20 per cent of the total value although for three separates this is exceeded. Obviously if the age of the biotite impurity is significantly different than the age of the hornblende or pyroxene the resulting date obtained may be in error. For two of the impure separates the age of the biotite impurity is known (table 18). The age of the impurities in the remaining separates can be reasonably assumed on the basis of biotite ages from adjacent samples (tables 16 and 17). Using either the known or assumed data for the biotite impurity the corrected Ar^{40}/K^{40} ratio can be calculated as follows:

Table 19.--Data on impure hornblende and pyroxene separates

Index No.	AK No.	Mineral Dated	Per cent Impurity	$\frac{K_2O_{imp.}}{K_2O_{tot.}}\%$	Total K_2O	Date (total)	Date (corr.)
7	276	Hornblende	1.5 biotite	13	0.96	1.75	1.75
5	273	Hornblende	2.8 biotite	8	1.86	1.69	1.70
22	275	Hornblende	1.2 biotite	14	0.62	1.73	1.73
39	266	Hypersthene	1.7 hornblende 1.3 biotite	20	0.59	2.20	2.32
45	215	Clinopyroxene	0.6 hornblende	10	0.04	6.4	----
47	269	Hornblende	1.0 biotite	18	0.45	1.82	1.82
47	272	Hornblende	1.8 biotite	50	0.28	1.74	1.74
48	255	Hornblende	2.0 biotite	24	0.66	1.74	1.74
50	256	Hornblende	1.0 biotite 4.0 hypersthene	5	1.77	2.41	2.44

Explanation:

(1) The K_2O contribution of the impurity is calculated from either known data or assumed value of 8 per cent K_2O for biotite.

(2) The per cent impurity is determined by counting 500 to 1000 or more grains in a carefully selected cut of the separate. The percentage reported is based strictly on the number of grains and likely represents an over estimation.

(3) Hornblende and pyroxene dates in tables which are not included above are free of any potassium bearing impurities.

$$\text{Ar}^{40}/\text{K}^{40} = \frac{[\text{total ppm Ar}^{40} \times 100 - (\% \text{ bio.} \times \text{ppm Ar}^{40}_{\text{biotite}})]}{[\text{total ppm K}^{40} \times 100 - (\% \text{ bio.} \times \text{ppm K}^{40}_{\text{biotite}})]}$$

Corrected dates were determined and these are given in table 19. The corrections for biotite rarely changed the date calculated from the data on the total separate. Sample AK 255 corrected for 2 per cent biotite shows no change because the biotite is very likely the same age as the hornblende (See muscovite date from same area, AK 257). Sample AK 265 may contain 1.7 b.y. old biotite as indicated by an adjacent sample (AK 192, table 17). Correction for this would raise the hornblende date to 2.44 b.y. Sample AK 266 contains biotite which, on the basis of a 1.53 b.y. Rb-Sr date, probably would give a date of about 1.5 b.y. Correction for this would raise the hypersthene date to an even more unreasonable 2.32 b.y. The remaining dates tabulated would not be changed by corrections unless the biotite impurities are anomalously young, a situation which is doubtful. Considering the probable values of the biotite corrections, the dates as originally calculated are used here.

DATES ON PYROXENES

Data for the pyroxene dates are summarized in table 20. The results obtained show some anomalies. Three of the five dates are completely anomalous and two are of dubious reliability. AK 245 is a clinopyroxene separated from a diabase dike from Quemont Mine, Quebec and the results are included here to supplement the other pyroxene data. The diabase dike has cross-cutting relations with an older basic dike from which hornblende is dated at about 1.7 b.y. (F. A. Campbell, personal communication). Two biotite and two hornblende dates from basement samples in the vicinity of AK 266 give results ranging from 1.68 to 1.75 b.y. Sample AK 281 is from a well located near the Churchill-Superior boundary and the date could possibly

represent a survival value, however, a Rb-Sr date of 1.53 b.y. obtained on co-existing microcline precludes this possibility. The two other dates are completely anomalous and the probable true ages are estimated in table 20. The most obvious way to interpret these dates is to assume that the basic requirement--no loss or gain of parent or daughter other than by radioactive decay--has not been fulfilled during the history of the minerals. With the limited data available it is possible only to speculate on the causes of the anomalous dates. Two such speculations are shown in table 20. Assuming that the potassium values are correct, the amount of excess Ar^{40} is calculated on the basis of the probable true age or age limits. Conversely, the amount of Ar^{40} is assumed to be correct and the deficiency in K^{40} is calculated. Until additional work is done on the dating of pyroxenes the problem must be considered not resolved. About all that can be said with certainty is that pyroxene dates must be interpreted with caution and additional study is necessary.

Rb-Sr DATES

Two Rb-Sr dates on microcline are shown in table 21. Neither date agrees with the K-Ar date determined on co-existing minerals. The microcline of sample 4678 contains considerable common Sr but the date is thought to be reproducible to $1.53 \pm .10$ b.y. (Goldich, 1962, personal communication). Microcline from the other sample (3633) has a more favorable Rb/Sr ratio; therefore, the date is more reliable. The lack of agreement between the microcline date and hypersthene date from 4678 is not surprising considering the uncertainties in pyroxene dating discussed above. It is thought that the difference between the 1.67 b.y. Rb-Sr date and the 1.20 b.y. K-Ar date on sample 3633 is significant. The Rb-Sr date is

Table 20.--Summary of pyroxene data.

Index No.	AK No.	Mineral	K ⁴⁰ ppm	Ar ⁴⁰ ppm	Date b.y.	Age b.y.	Excess Ar ⁴⁰ ppm	Deficiency K ⁴⁰ ppm
39	266	Hypersthene	0.59	0.1455	2.20	1.53	0.0632	0.45
4	281	Hypersthene	0.11	0.0219	1.92			
45	215	Clinopyroxene	0.04	0.1317	6.4	2.4	0.121	0.40
--	245	Clinopyroxene	0.015	0.03169	5.6	<1.7	>0.029	>0.18
50	258	Clinopyroxene: Hypersthene=4:1	0.04	0.0209	3.3	<2.4 >1.7	>0.009 <0.014	>0.03 <0.09

Explanation:

(1) The probable real ages are based either on co-existing mineral dates or geologic relations with dated rocks:

AK 266--co-existing microcline dated at 1.53 b.y. by Rb-Sr.

AK 215--co-existing hornblende dated at 2.35 b.y. (AK 216)

AK 245--pyroxene is from diabase dike which intrudes older diabase dike dated at 1.7 b.y. (F.A. Campbell, personal communication)

AK 258--pyroxene from diabase dike which intrudes gneisses dated at 2.41 b.y. (AK 256) and may be cut by younger granites presumably about 1.7 b.y. old.

(2) The excess Ar⁴⁰ is calculated on the assumption that since the time of formation potassium has been lost only by radioactive decay.

(3) The deficiency in K⁴⁰ is calculated on the assumption that Ar⁴⁰ has been derived from the radioactive decay of potassium within the mineral and none has been added from outside sources.

typical for the basement of Saskatchewan. The younger biotite date may well represent a later event, the nature of which is not known.

Table 21.--Rb-Sr dates

Index No.	Sample No.	Mineral	*Sr ⁸⁷ /Sr ⁸⁷ total (per cent)	Rb/Sr	Date(b.y.)	K-Ar Date	Mineral	AK No.
27	3633	Microcline	50	10	1.67	1.20	Biotite	264
39	4678	Microcline	15	1.9	1.53	2.20	Hypersthene	266

SUMMARY AND CONCLUSIONS

The following sections contain a brief summary of the results and conclusions obtained during the present study. Regional interpretations of Precambrian of the western Canada sedimentary basin have previously been made (Burwash, et al, 1961; 1962). The main emphasis will be on the results obtained during the present study of the basement of Saskatchewan, Manitoba and adjacent areas; and the dating completed on outcrop samples. Dates from other laboratories are also employed in the discussion (fig. 20).

Churchill-Superior Boundary

One of the major purposes of the present study was to determine the basement position of the boundary between the Churchill and Superior geologic provinces. This been achieved by K-Ar dating although geophysical studies have been more successful in locating precisely the position of the boundary zone in the basement. The dates obtained from basement cores indicate that the boundary position as shown by the Nelson River gravity low is reasonable (fig. 13). From the shield area it curves sharply to the south and continues into North Dakota. The boundary position is not known in South Dakota although it is probable that it curves to the east and connects with the geologically and geochronologically determined contact between the Superior province and Penokean fold belt of Minnesota. Dating of basement samples in South Dakota would confirm or disprove this speculation.

In the shield area of Manitoba north of the northern limits of the gneissic boundary zone K-Ar dates range from 1.61 to 1.83 b.y. and the average is 1.74 b.y. In Area II of northern Saskatchewan the average of

K-Ar dates is 1.70 b.y. and the range is from 1.55 to 1.87 b.y. These dates represent the time of metamorphism, folding, and intrusion accompanying the Hudsonian orogeny. No dates older than expected for the Churchill province have been determined in these two areas. It is not known how much older than about 1.7 b.y. the rocks actually are. Certainly many are probably Lower Proterozoic but these must have been deposited on more ancient rocks. This older basement may have been either oceanic in character, or have formed the part of the Superior province which possibly extended much further west than shown by the present limits. Adjacent to the Slave province recent work has shown that Lower Proterozoic sediments were deposited on a basement composed of continental Archean rocks and that the Hudsonian orogeny affected both the younger sedimentary rocks and the older basement in part. It is likely that a similar situation occurred at the flanks of the Superior province. Animikie sediments of Minnesota and adjacent parts of Ontario were deposited at least in part on the older Superior craton but the extent of the older continental basement is not known.

Geologic evidence in northern Manitoba and Saskatchewan can be interpreted as being suggestive of the presence of a Superior continental shelf prior to the Hudsonian orogeny. The Kisseynew gneisses of Manitoba and many of the rocks exposed in the shield of Saskatchewan appear to have been derived from sedimentary rocks more typical of shelf than eugeosynclinal environments. Calc-silicate rocks derived from carbonates are widespread and many of the abundant amphibolites can be interpreted as being of carbonate origin; however, the possibility that they were originally volcanics cannot be dismissed. Schists and gneisses derived from pelitic sediments and arkoses are common, and pure quartzites are locally present. The classical greenstone-greywacke sequence occurs in places, notably in the Lynn Lake, Flin Flon, and Waddy-Windrum Lakes area, but it is not nearly as common

as in the Superior province. Basement representatives of shelf deposits may be the metaquartzite (4221) and iron formation (4484-85) of Saskatchewan and a marble described from northeastern Montana by Meek (1958). The grain of the Churchill province of Saskatchewan has the typical northeast trend, however, in northern Manitoba the fabric trends easterly. It is possible that these structures in northern Manitoba are related to those in the Superior province or were caused by stresses during the Hudsonian orogeny which were oriented differently than those which produced the northeasterly trends in Saskatchewan.

Within the Nelson River gneissic zone and some distance to the south in exposed parts of the shield, K-Ar dating has revealed the widespread effects of the Hudsonian orogeny on the older Superior craton. Biotite and hornblende from Thicket Portage yields dates of 1.72 b.y. and 2.41 b.y. respectively. These dates are from the same band of gneisses and the biotite was apparently updated by the Hudsonian event, while the more resistant hornblende retained its argon. Biotite from a hypersthene granite nearby has been dated at 2.40 b.y. indicating the variability of the Hudsonian effects within a relatively small area. Biotite from other areas within the gneissic zone has given ages of about 1.7 b.y. The nature of the Hudsonian effects south of the boundary zone are not completely known. In some areas, however, granitic intrusions occurred at the time of this orogeny. Dates of 2.50, 2.08, 2.07, and 1.85 b.y. have been obtained at Cross Lake. The older date indicates the time of the Kenoran orogeny. The 1.85 b.y. dates in on a post-Cross Lake group granitic intrusion. Intermediate values and a 2.19 b.y. date near the north end of Lake Winnipeg are Archean survival values. Similar relations have been noted near Gods Lake where a "young" granite has been dated at 1.64 b.y. and a gneissic

granite at 2.20 b.y. In the same area pre- and post-Oxford group granitic rocks are dated at 2.62 b.y. and 2.38 b.y. respectively.

A situation similar to that described above undoubtedly exists in the basement areas adjacent to the boundary zone, but because of limited samples only one such example has been found. In southwestern Manitoba, east of the assumed boundary zone, biotite from a gneiss is dated at 1.93 b.y. This date is probably the result of updating of Archean rocks by the Hudsonian orogeny.

Basement Extents of Churchill and Superior Provinces

The Precambrian basement of Manitoba appears to be mainly of Superior age. Biotite from two cores gives dates of 2.43 b.y. and 2.49 b.y. and a third is the aforementioned survival value. Two samples from eastern North Dakota yielded similar dates of 2.44 b.y. and 2.49 b.y. and the basement of the eastern half of the state probably belongs to the Superior province.

The basement of the sedimentary area of Saskatchewan belongs mostly to the Churchill province although some dates deviate from the typical range of 1.65 to 1.85 b.y. In southeastern Saskatchewan, two biotite dates of 1.51 b.y. and 1.57 b.y. were determined. To the south in North Dakota microcline gives a Rb-Sr date of 1.53 b.y. These three dates are similar to those obtained from the Black Hills Precambrian further to the south. The 1.51 b.y. biotite is from a well located approximately on the gravity low which marks the boundary zone. The rock is very fresh, fine-grained quartz monzonite. The 1.57 b.y. biotite is from a cordierite gneiss and the Rb-Sr date is on a pyroxene granulite that has undergone some deformation. At the present time it is not known whether these slightly younger dates represent an actual post-Hudsonian event or merely the final phases of the Hudsonian orogeny.

Two samples from southwestern Saskatchewan also gave K-Ar dates somewhat less than expected for Churchill terrane. Biotite from a fresh porphyritic granite was dated at 1.20 b.y., but co-existing microcline gave a date of 1.67 b.y. by the Rb-Sr method. Hornblende from a nearby well gave 1.49 b.y. by the K-Ar method. The porphyritic rhyolite from which the hornblende was separated is somewhat altered and the 1.49 b.y. date could be interpreted as a Churchill survival value. The unaltered nature of the porphyritic granite suggests that it was merely heated at 1.20 b.y. ago or later and did not undergo dynamic metamorphism. These two samples are from a somewhat disturbed area in that basement faulting may have caused some of the relief now evident on the basement surface. Possible cryptovolcanic structures north of the dated samples may be an indication of Phanerozoic tectonic activity although these structures could also be the result of salt tectonics in post-Devonian time. At the present time it seems hazardous to be too inflexible in the interpretation of these dates. The Rb-Sr date of 1.67 b.y. suggests that the basement rocks crystallized during the Hudsonian orogeny and the K-Ar dates indicate a subsequent event at 1.20 b.y. or later.

The eleven remaining reliable dates from the Saskatchewan basement range from 1.63 b.y. to 1.78 b.y. and the average is 1.71 b.y. Three of the eleven are on hornblende and eight are on biotite. The rock types dated include three quartz monzonites, two biotite-quartz-feldspar gneisses, two biotite schists, one iron formation, and one amphibolite. Biotite from the two schists gave the lowest values of 1.63 b.y. and 1.64 b.y. Just as in northern Manitoba and most of northern Saskatchewan, no dates older than those typical of the Churchill province have been determined from this basement area.

The Churchill province appears to extend south into Montana. Biotite and hornblende separated from samples from the same well give dates of 1.72 b.y.

and 1.77 b.y. respectively. Biotite and hornblende dates of 1.75 b.y. and 1.79 b.y. are obtained from rocks cropping out in the Little Rocky Mountains. Samples from the Little Belt Mountains yield a biotite age of 1.75 b.y. and a hornblende date of 1.71 b.y. U-Pb and Rb-Sr dating, however, suggests that the Precambrian rocks of the Little Belt Mountains may actually be Archean in which case the area has undergone two orogenic cycles the last of which was the Hudsonian orogeny which effectively outgassed the biotite and hornblende.

Basement Composition and Structure

The composition of the basement of Saskatchewan appears to be similar to the total shield composition of Saskatchewan. Silicic and intermediate plutonic rocks predominate. Agreement between the assumed basement composition and that determined for the adjacent shield area is rather good as shown in table 15; however, it is presumptuous to assume that the samples from 43 basement wells represent the composition of the total basement area. If additional samples become available, it is likely that the evidence for petrologic similarities between areas of the shield and of the basement would be strengthened. It may become possible to delineate certain basement areas characterized by various rock types and correlate these with portions of the shield. It has been possible to do this only in a very qualitative fashion during the present study. Samples from the northern line of wells in Saskatchewan seem to agree in rock type with the regional geology of the adjacent shield.

The basement of southwestern Saskatchewan is distinctive in composition, structure, and determined ages. Six of the eight basement wells penetrated igneous rocks in which albite is the typical plagioclase. All of the other basement samples contain oligoclase and andesine. Four of the six samples

are porphyritic and a high level of emplacement is suggested. The two porphyritic rhyolites are either extrusive or hypabyssal and the two porphyritic granites were probably emplaced in the epizone. The basement surface of this area has considerably more local relief than found elsewhere. Some of this relief existed in pre-Deadwood time and may be erosional in nature; however, late Precambrian faulting could also have caused some of the relief. The proximity of the area to Montana where basement faulting is common may support this idea. If the Elbow and Gilroy structures are attributed to a cryptovolcanic origin, then basement faults or zones of weakness are suggested because the forces that cause such structures in flat-lying sediments surely penetrate the basement. If the structures are the result of salt-solution and subsequent collapse, there may be no relation to the basement. It is worthy of note that this area is fairly close to a projection of the Idaho porphyry belt which on the basis of crude alignment of intrusions and earthquake epicenters can be interpreted as a major zone of crustal weakness. It is known that some of the basement faults in Montana are very ancient in origin and it is possible that the porphyry belt represents an old crustal flaw which has persisted and been reactivated at various times since Lower Proterozoic or even Archean time. That an event later than the Hudsonian orogeny did occur in the area is indicated by the 1.20 b.y. date obtained from the porphyritic granite dated at 1.67 b.y. by the Rb-Sr method. The diabase dike intruded into the Athabasca sandstones at 1.23 b.y. indicates that regional stresses were active at that time to produce fractures of sufficient magnitude to tap basaltic magma. Perhaps the 1.20 b.y. biotite is related to this event. The possibility of Tertiary intrusions in the area which may not have penetrated overlying sedimentary rocks cannot be discounted at the present time and such intrusions could also cause updated biotite.

Structural features within other parts of the basement of Saskatchewan are poorly known. Very few faults have been recognized in the sedimentary rocks and basement control has not been proven for these. In south-central Saskatchewan faults are inferred but there is some controversy as to whether these were caused by basement faulting, salt solution, or other mechanisms. Tectonic instability of the basement in recent times is indicated by the 1909 Regina earthquake and this fact plus convincing arguments by various authors familiar with the area have inclined the writer to believe that re-activation of basement faults has been operative during the past. In central Saskatchewan the Meadow Lake escarpment may be the result of either a trans-current fault or reversal of movement along a dip-slip fault. South of Lac la Ronge there is evidence for post-Cretaceous movement along basement faults. Basement faulting has been proposed to explain some features of the sedimentary area of Manitoba but salt tectonics are also suggested.

It is possible that basement control on structures in Saskatchewan and Manitoba has been more extensive than so far suggested. The adjacent shield area and the basement of Montana are dissected by many faults of major proportions. The basement of Saskatchewan and Manitoba is undoubtedly similar in this respect. Depending on the depth of burial of the basement, later imposed stresses may be completely or partially relieved along the older faults. Basement control was so extensive in Montana and probably in parts of North Dakota that it seems unlikely that the tectonic style changes abruptly at the 49th Parallel and all structures to the north have been produced by solution and removal of Devonian evaporites. Very likely both mechanisms were operative.

Relation of Dates to Rock Types

During an attempt to determine possible relations between rock types and K-Ar dates an interesting situation was noted. In figure 21 modal quartz, K-feldspar, and plagioclase are plotted for silicic plutonic rocks of both igneous and metamorphic origin. The points represent 27 basement samples and 7 outcrop samples. Their silicic compositions are indicated by the sum of quartz, K-feldspar, and plagioclase. This is shown below.

<u>Number of Samples</u>	<u>Sum of Quartz+K-feldspar+ Plagioclase</u>
19	>90
14	80 to 90
1	= 74

The plagioclase compositions range from An 5 to An 34 and the average is An 23.

The K-Ar ages of the dated samples are indicated and the location of the samples with regard to either the Superior or Churchill province is shown by open or closed circles (fig. 21). The major concentration of Churchill samples is in the granitic field whereas the Superior samples are more granodioritic in composition. The previously discussed uncertainties in the modes affect the reliability of the diagram. Another complicating factor is the perthitic nature of most of the K-feldspar and no correction has been made for this. However, most of the plagioclase is antiperthitic so this will somewhat offset the amount of plagioclase in the perthite. The Superior samples are represented by five from the basement and six from the shield. Of those from the shield, three are from Cross Lake, two from Gods Lake, and one from Thicket Portage. Thus, there is a distinct bias towards central Manitoba. One of the Churchill samples is from the shield of Manitoba and the remainder are from the basement of Saskatchewan.

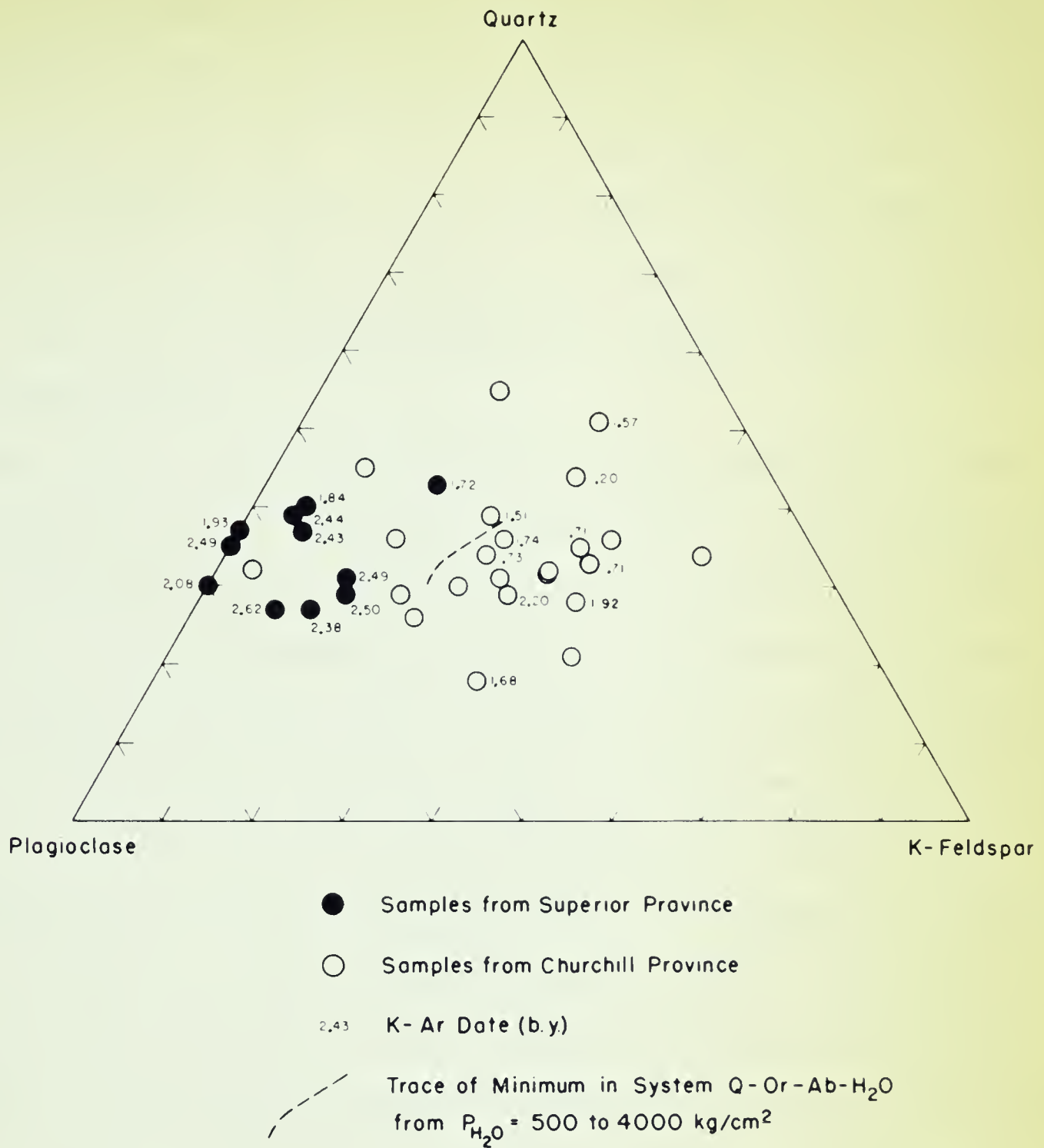


Figure 21.--Plot of modal quartz, K-feldspar, and plagioclase for silicic plutonic rocks.

It would be somewhat hasty to conclude that the plutonic rocks of the western part of the Superior province are typically low in potassium whereas those from the basement area of the Churchill province are high in potassium even though the results suggest such a conclusion. Additional data would undoubtedly broaden the two fields shown because normal granites certainly exist in the Superior province as do granodiorites in the Churchill province. It may also be true that the position of the major concentrations would remain about the same as shown in figure 21. On this premise, the following speculations are made.

Any attempt to explain the apparent relations shown must take into consideration the origin of plutonic rocks which is a very debatable question. If one assumes that many of the granitic rocks now exposed in the shield and present in the basement were formed by high grade metamorphism and anatexis of pre-existing sedimentary rocks, an assumption not unrealistic in the writer's opinion, then a possible solution for the relations shown in figure 21 can be obtained. In many parts of the Superior province the typical volcanic-sedimentary belts contain sodium rich rocks. The greenstones are usually spilitic in nature and the associated sediments contain large quantities of greywacke, the only sedimentary rock in which sodium exceeds potassium. Therefore, in the Superior province the "raw material" suitable for the production of granodioritic rocks is present. Isochemical metamorphism of a greywacke would produce a gneiss approaching a granodiorite in composition. Melting, if carried beyond the granite minimum, would produce a granodioritic magma.

A review of the geology of the shield area of the Saskatchewan Churchill province indicated that many of the gneisses and metasediments were not derived from typical eugeosynclinal sequences. Meta-arkoses are fairly abundant as are rocks derived from pelitic sediments. Magmas produced by

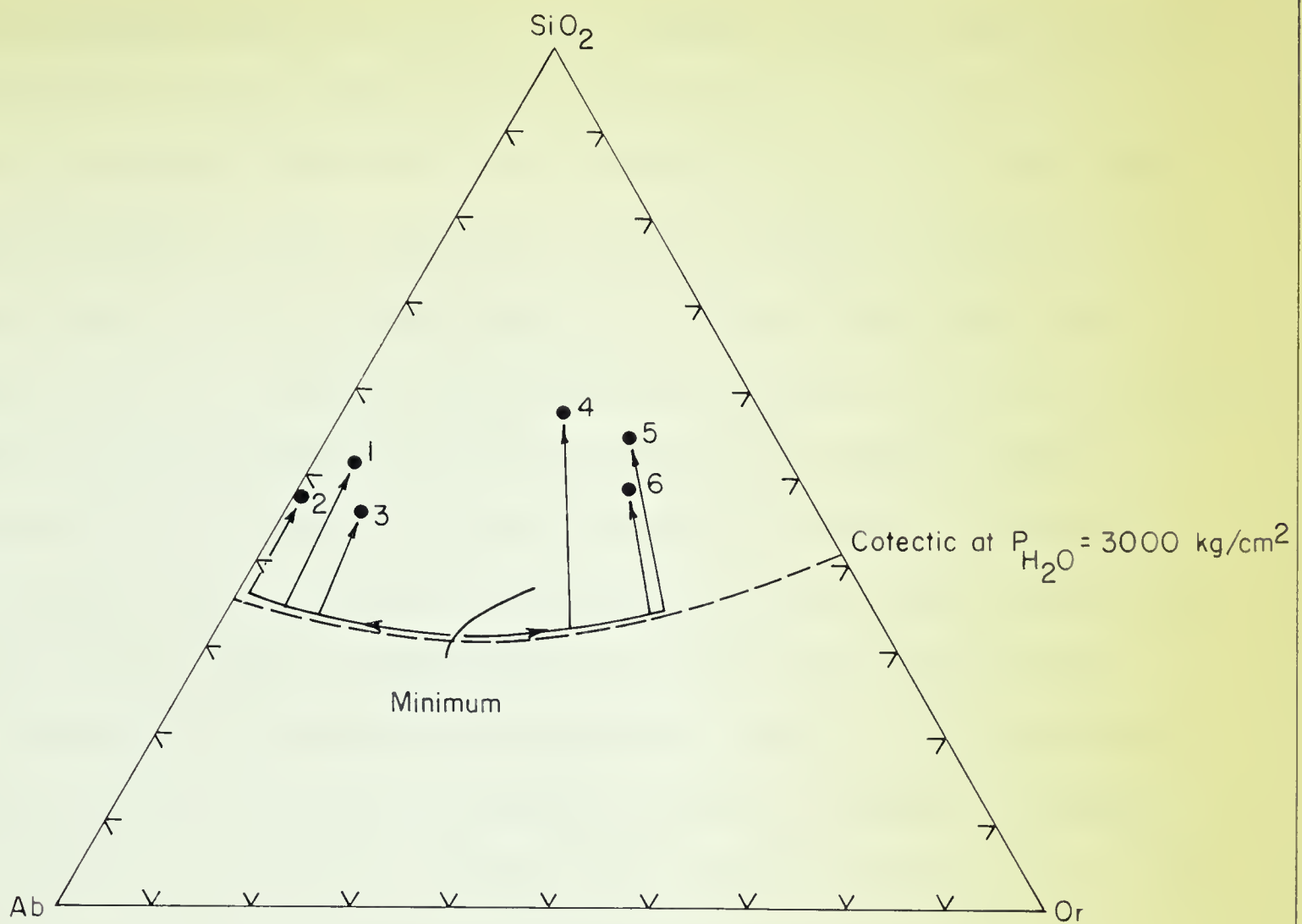
melting of sediments of this nature could be potassium rich.

In figure 22 mesonorms of average compositions for greywacke, arkose, and shale are plotted on the Q-Or-Ab system of Tuttle and Bowen (1958). Initial melting of the bulk compositions shown results in liquid whose composition is that of the granite minimum. With increased temperature the composition of the liquid migrates along the cotectic trough either to the right or left depending on the bulk composition of the material being melted. In the case of greywackes the liquid becomes more sodium rich and for shales and arkoses the liquid becomes enriched in potassium. Thus, it appears possible for the compositions of the dominant sedimentary rocks to control the nature of the igneous rocks of an area providing that anatexis is an operative factor in the formation of silicic magmas. The apparent relations shown by figure 21 could possibly be explained by this mechanism. Gneisses produced by metamorphism would reflect the initial composition of the parent rock and the same is true for the magmas produced by ultrametamorphism.

The ideas presented above are pure speculation and perhaps it would be better not to make interpretations at the present time. Other mechanisms could be invoked to explain the relations such as regional potash metasomatism which appears to have occurred in some areas of Saskatchewan.

Precambrian History

The oldest recognizable rocks of Archean time in most places are thick accumulations of volcanic and associated sedimentary rocks. These include the Ely greenstones of Minnesota, Keewatin group of Ontario, Rice Lake group and Hayes River group of Manitoba, and probably parts of the Yellowknife group of the Northwest Territories. In the Rainy Lake region of Ontario and undoubtedly in other places the deposition of volcanics was preceded by thick deposits of sediments; in the Rainy Lake area these are



1. Average greywacke (Pettijohn, 1957)
- 2, 3. Couthiching greywackes
4. Average shale (Clarke, 1911)
5. Average Precambrian slate (Nanz, 1953)
6. Average arkose (Pettijohn, 1957)

Solid curves are theoretical paths followed by liquids during increasing temperature.

Figure 22.--Plot of normative Q, Or, and Ab for some average sedimentary rock compositions.

the Coutchiching metasediments and gneisses. It is extremely unlikely that all of the volcanic groups are correlative in a strict sense but they were probably deposited prior to 2.6 b.y. ago. Geologic evidence indicates that these rocks were folded, metamorphosed, and intruded by igneous rocks. In Minnesota and Ontario this event is the Laurentian orogeny but other than occurring more than 2.6 b.y. ago it has not been satisfactorily dated. Following this or similar events erosion occurred and sedimentary rocks were deposited on the older greenstone-granite complexes. These are generally referred to as Timiskamian-types and in Minnesota and adjacent parts of Ontario the Knife Lake and Seine groups are representatives. In Manitoba rocks of similar nature belong to the San Antonio, Island Lake, Oxford, and Cross Lake groups. Most of these typically contain conglomerates with cobbles and boulders of the pre-existing rocks. After or quite possibly during the depositions of these sedimentary groups the Kenoran or Algoman orogeny occurred. It may have spanned a time interval from 2.6 b.y. to 2.4 b.y. but igneous activity and metamorphism appears to have been completed by about 2.4 b.y. ago. This event affected rocks of the Superior, Slave, and Beartooth provinces, and was the final consolidating orogeny for these continental nuclei.

At the end of Archean time the basic framework was set for later geologic events. A continent or continents in the form of three nuclei existed. The areal extent of these embryonic cratons at that time is not known. According to the theory of continental accretion they may not have been much larger than their present limits indicate but this seems untenable in light of recent work in the Northwest Territories. It is likely that continental shelves flanked all three of the nuclei and the possibility that these nuclei were completely joined cannot be denied. The Slave province existed as far south as the present location of Lake Athabasca and possibly as far

east as Hudson Bay. The Beartooth province probably extended north beyond the present Little Belt Mountains. The western extent of the Superior province is thought to have been further west than presently indicated by the Churchill-Superior boundary although absolute evidence for this speculation is lacking.

During Lower Proterozoic time the Archean cratonic areas were being subjected to weathering and erosion; sediments of various types were being deposited in adjacent seas. It was during this time that the Huronian sediments of southern Ontario and the economically important Animikie and similar iron-bearing sediments were laid down on the flanks of the Superior province. The Nonacho and Hurwitz groups of the Northwest Territories, and possibly part of the Tazin group of northern Saskatchewan were deposited in Lower Proterozoic time. The Kisseynew, Amisk, Wasekwan, Missi, and Sickle rocks of Manitoba; and great volumes of unnamed sedimentary rocks of other areas of the Churchill province may have been deposited during this period, although only minimum radioactive ages for these rocks are available. The possibility that some of these rocks are Archean, such as the Amisk and Wasekwan metavolcanics of Manitoba, cannot be discounted at the present time.

There seems little doubt that the Hudsonian orogeny occurred between approximately 1.85 and 1.65 b.y. ago. Late phases may have been active until 1.50 b.y. During this event, Lower Proterozoic sediments were folded, faulted, metamorphosed, granitized, and intruded by a variety of igneous rocks. The regional structures in Saskatchewan, which were probably produced during the Hudsonian orogeny, appear to parallel the Churchill-Superior boundary zone. In northern Saskatchewan, isoclinal folding occurred, producing folds with axes trending northeast. Further south in the present basement area, the fold axes probably trend about northerly. It is difficult to

visualize the situation at the end of Lower Proterozoic time. Undoubtedly, large mountain ranges were formed during the Hudsonian orogeny, but the width, length, and general shape of the Churchill province are difficult to rationalize in terms of more recent orogenic belts.

Middle Proterozoic time is represented by the Martin formation, the Athabasca series, and the Dubawnt series all of northern Saskatchewan and adjacent parts of the Northwest Territories. The Sioux quartzite of Minnesota was also deposited about this time. Along the western margin of the newly formed cratonic area, Beltian deposition and associated magmatism were taking place (Hunt, 1961). About 1.2 b.y. ago faulting occurred and diabase dikes were emplaced in the Athabasca series. Sedimentary and volcanic rocks of the Keweenaw of Minnesota belong in part to this period. The Grenville orogeny of eastern North America closed Middle Proterozoic time and in Minnesota the Duluth gabbro and associated intrusions were emplaced.

Upper Proterozoic events have not been recognized in the area studied. The younger East Kootenay orogeny (See Burwash et al, 1961) was restricted to the Beltian terrane farther to the west.

The foregoing discussion is by necessity very generalized, and without doubt the Precambrian history of the area was much more complicated than indicated above. Lower Proterozoic time alone is approximately equivalent in length to the whole of the Phanerozoic eon, a fact which makes the problem of determining the geological history difficult. The geologic record is so confused that it is doubtful if the complexities will ever be resolved in the detail that is known for the Phanerozoic.

REFERENCES CITED

- Abbey, S., and Maxwell, J. A., 1960, Determination of potassium in micas: Chem. in Canada, v. 12, p. 37-41.
- Agarwal, R. B., 1960, Interpretation of aeromagnetic data in west central Saskatchewan: Saskatchewan Dept. Mineral Resources, Rept. 63, 17 p.
- Alcock, F. J., 1935, Mudjatik-Haultain area, Saskatchewan: Canada Geol. Survey Mem. 180, 16 p.
- 1936, Geology of Lake Athabasca region, Saskatchewan: Canada Geol. Survey Mem. 196, 41 p.
- 1939, Oliver Lake, northern Saskatchewan: Canada Geol. Survey Map 528A.
- Alcock, F. J., Sproule, J. C., and Downie, D. L., 1941a, Porter Lake, northern Saskatchewan: Canada Geol. Survey Map 580A.
- 1941b, Haultain River, northern Saskatchewan: Canada Geol. Survey Map 579A.
- Aldrich, L. T., Wetherill, G. W., Davis, G. L., and Tilton, G. R., 1958, Radioactive ages of micas from granitic rocks by Rb-Sr and K-A methods: Am. Geophys. Union Trans., v. 39, no. 6, p. 1124-1134.
- Alpha, A. G., 1955, Tectonic history of north-central Montana: Billings Geol. Soc. Guidebook, 6th Ann. Field Conf., p. 129-142.
- 1958, Tectonic history of Montana: Billings Geol. Soc. Guidebook, 9th. Ann. Field Conf., p. 57-68.
- Alpha, A. G., and Fanshawe, J. R., 1954, Tectonics of northern Bighorn basin area and adjacent south-central Montana: Billings Geol. Soc. Guidebook, 5th. Ann. Field Conf., p. 72-79.
- Am. Assoc. Petroleum Geologists, and U. S. Geol. Survey, 1961, Tectonic map of the United States.
- Andrichuk, J. M., 1961, Stratigraphic evidence for tectonic and current control of upper Devonian reef sedimentation, Duhamel area, Alberta, Canada: Am. Assoc. Petroleum Geologists Bull., v. 45, no. 5, p. 612-632.
- Armstrong, J. E., 1941, Wekusko, Manitoba: Canada Geol. Survey Map 665A.
- Armstrong, H. S., 1960, Marbles in the "Archean" of the southern Canadian shield: Internat. Geol. Cong., 21st, Norden, 1960, Pt. 9, p. 7-20.
- Baadsgaard, H., Goldich, S. S., Nier, A. O., and Hoffman, J. H., 1957, The reproducibility of A^{40}/K^{40} age determinations: Am. Geophys. Union Trans. v. 38, no. 4, p. 539-542.
- Baadsgaard, H., Lipson, J., and Folinsbee, R. E., 1961, The leakage of radio-genic argon from sanidine: Geochim. et Cosmochim. Acta, v. 25, p. 147-157.

- Baillie, A. D., 1951, Silurian geology of the interlake area: Manitoba Dept. Mines and Nat. Resources, Mines Branch Pub. 50-1, 82 p.
- 1952, Ordovician geology of Lake Winnipeg and adjacent areas: Manitoba Dept. Mines and Nat. Resources, Mines Branch Pub. 51-6, 64 p.
- Barnes, T. R., 1953, Williston basin: Am. Assoc. Petroleum Geologists Bull., v. 37, no. 2, p. 340-354
- Barry, G. S., 1959, Geology of the Oxford House-Knee Lake area: Manitoba Dept. Mines and Nat. Resources, Mines Branch Pub. 58-3
- 1960, Geology of the western Oxford Lake-Carghill Island area: Manitoba Dept. Mines and Nat. Resources, Mines Branch, Pub. 59-2, 37 p.
- 1961, Geology of the Gods Narrows area: Manitoba Dept. Mines and Nat. Resources, Mines Branch Pub. 60-1, 33 p.
- Bateman, J. D., and Harrison, J. M., 1945, Mikanagan Lake, Manitoba: Canada Geol. Survey Map 832A.
- 1946, Sherridon, Manitoba: Canada Geol. Survey Map 862A.
- Bishop, R. A., 1954, Saskatchewan exploratory progress and problems, in Western Canada Sedimentary Basin (Rutherford volume): Tulsa, Am. Assoc. Petroleum Geologists, p. 474-485.
- Blackadar, R. G., and Fraser, J. A., 1960, Precambrian geology of Arctic Canada, a summary account: Canada Geol. Survey Paper 60-8, 24 p.
- Blake, D. A. W., 1956a, Oldman River map-area, Saskatchewan: Canada Geol. Survey Mem. 279, 52 p.
- 1956b, Geological notes on the region south of Lake Athabasca and Black Lake, Saskatchewan and Alberta: Canada Geol. Survey Paper 55-33 12 p.
- Brown, I. C., and Wright, G. M., 1957, Proterozoic rocks of Northwest Territories and Saskatchewan, in The Proterozoic of Canada: Royal Soc. Canada Spec. Pub. 2, p. 79-92.
- Bucher, W. H., Thom, W. T., Jr., and Chamberlin, R. T., 1934, Geologic problems of the Beartooth-Bighorn region: Geol. Soc. America Bull., v. 45, no. 2, p. 167-188
- Buckham, A. F., 1944, Athapapuskow Lake, Manitoba: Canada Geol. Survey Map 807A.
- Buddington, A. F., 1959, Granite emplacement with special reference to North America: Geol. Soc. America Bull., v. 70, no. 6, p. 671-747.
- Budding, A. J., 1955, The geology of the Settee Lake area (east half): Saskatchewan Dept. Mineral Resources, Rept. 17, 19 p.
- Budding, A. J., and Kirkland, S. J. T., 1956, The geology of the Reindeer River area: Saskatchewan Dept. Mineral Resources, Rept. 22, 44 p.
- Burwash, R. A., 1957, Reconnaissance of subsurface Precambrian of Alberta: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 1, p. 70-103.

- Burwash, R. A., 1962, Geology of the Rusty Lake area: Manitoba Dept. Mines and Nat. Resources, Mines Branch, Pub. 60-3, 31 p.
- Burwash, R. A., and Baadsgaard, H., 1962, Yellowknife-Nonacho age and structural relations: Royal Soc. Canada Spec. Pub. 3, in press.
- Burwash, R. A., Baadsgaard, H., and Peterman, Z. E., 1962, Precambrian K-Ar dates from the western Canada sedimentary basin: Jour. Geophys. Research, v. 67, no. 4, p. 1617-1625.
- Burwash, R. A., Baadsgaard, H., Peterman, Z. E., and Hunt, G. H., 1961, Precambrian history of the western Canada sedimentary basin (abs.): Alberta Soc. Petroleum Geologists, Calgary, 1961.
- Byers, A. R., 1949, The geology of the Waddy Lake area: Saskatchewan Dept. Mineral Resources, Rept. 1, 36 p.
- 1957, Geology and mineral deposits of the Hanson Lake area, Saskatchewan: Saskatchewan Dept. Mineral Resources, Rept. 30, 47 p.
- Byers, A. R., and Dahlstrom, C. D. A., 1954, Geology and mineral deposits of the Amisk-Wildnest Lakes area, Saskatchewan: Saskatchewan Dept. Mineral Resources, Rept. 14, 169 p.
- Camsell, Charles, 1916, An exploration of the Tazin and Taltson Rivers, Northwest Territories: Canada Geol. Survey Mem. 84, 124 p.
- Canada Geol. Survey, 1946, Geological map of Manitoba: Map 850A.
- 1947, Geological map of Saskatchewan: Map 895A.
- 1957, Geophys. Papers 305G-307G incl., 319G-324G incl., 495G-496G incl., 552G-587G incl.
- Catanzaro, E. J., and Kulp, J. L., 1960, U-Pb ages in the Little Belt Mountains, Montana (abs.): Geol. Soc. America Bull., v. 71, no. 12, p. 1841.
- Chamberlin, R. T., 1945, Basement control in Rocky Mountain deformation: Am. Jour. Sci. (Daly volume), v. 243a, p. 98-116.
- Cheesman, R. L., 1956, The geology of the Mari Lake area, northeastern Saskatchewan: Saskatchewan Dept. Mineral Resources, Rept. 23, 40 p.
- 1959, The geology of the Wapus Bay area (west half), Saskatchewan: Saskatchewan Dept. Mineral Resources, Rept. 35, 21 p.
- Christie, A. M., 1953, Goldfields-Martin Lake map-area, Saskatchewan: Canada Geol. Survey Mem. 269, 126 p.
- Colborne, G. L., 1960, The geology of the Clut Lakes area (west half), Saskatchewan: Saskatchewan Dept. Mineral Resources, Rept. 43, 28 p.
- 1961, The geology of the Clut Lakes area (east half), Saskatchewan: Saskatchewan Dept. Mineral Resources, Rept. 58, 31 p.
- Collins, C. B., Farquhar, R. M., and Russell, R. D., 1954, Isotopic constitution of radiogenic leads and the measurement of geological time: Geol. Soc. America Bull., v. 65, no. 1, p. 1-22.

- Compston, W., and Jeffery, P. M., 1961, Metamorphic chronology by the rubidium-strontium method: *Annals New York Acad. Sci.*, v. 91, art. 2, p. 185-191.
- Cooper, G. G., 1956, The Tyler formation and basement faulting: *Billings Geol. Soc. Guidebook*, 7th Ann. Field Conf., p. 82-85.
- Cumming, G. L., Wilson, J. T., Farquhar, R. M., and Russell, R. D., 1955, Some dates and subdivisions of the Canadian shield: *Geol. Assoc. Canada Proc.*, v. 7, p. 27-79.
- Currie, K. L., 1961a, Whiskey Jack Lake, Manitoba: *Canada Geol. Survey Map* 52-1960.
- 1961b, Oxford House, Manitoba: *Canada Geol. Survey Map* 21-1961.
- Damon, P. E., and Kulp, J. L., 1958, Excess helium and argon in beryl and other minerals: *Am. Mineralogist*, v. 43, p. 433-459.
- Dawson, A. S., 1941, Assean-Split Lakes area: *Manitoba Dept. Mines and Nat. Resources, Mines Branch, Geol. Rept.* 39-1, 32 p.
- deMille, George, 1958, Pre-Mississippian history of the Peace River arch: *Alberta Soc. Petroleum Geologists Jour.*, v. 6, no. 3, p. 61-68.
- 1960, The Elbow structure of south-central Saskatchewan: *Alberta Soc. Petroleum Geologists Jour.*, v. 8, p. 154-162.
- Derry, D. R., 1950, Tectonic map of Canada: *Geol. Assoc. Canada*.
- Dix, W. F., 1948, Geology of the Gods Lake area: *Manitoba Dept. Mines and Nat. Resources, Mines Branch, Pub.* 47-4, 7p.
- Downie, D. L., 1936, Granville Lake sheet (west half), Manitoba: *Canada Geol. Survey Map* 343A.
- Eardley, A. J., 1951, *Structural Geology of North America*: New York, Harper and Brothers, 624 p.
- Eckelmann, W. R., and Kulp, J. L., 1956, Uranium-lead method of age determination, part I: the Lake Athabasca problem: *Geol. Soc. America Bull.*, v. 67, p. 35-54.
- 1957, Uranium-lead method of age determination, part II: North American localities: *Geol. Soc. America Bull.*, v. 68, p. 1117-1140.
- Edie, R. W., 1956, The Avonlea fault block, southern Saskatchewan: *Alberta Soc. Petroleum Geologists Jour.*, v. 4, no. 6, p. 129-133.
- 1958, Mississippian sedimentation and oil fields in southeastern Saskatchewan: *Am. Assoc. Petroleum Geologists Bull.* v. 42, no. 1, p. 94-126.
- Ellis, S. C., Downie, D. L., and Sproule, J. C., 1941, Upper Clearwater River, northern Saskatchewan: *Canada Geol. Survey Map* 578A.
- Fahrig, W. F., 1958, Wollaston Lake, Saskatchewan: *Canada Geol. Survey Map* 27-1957.

- Fahrig, W. F., 1961, The geology of the Athabasca formation: Canada Geol. Survey Bull. 68, 41 p.
- Folinsbee, R. E., Baadsgaard, H., and Lipson, J., 1960, Potassium-argon time scale: Internat. Geol. Cong., 21st, Norden 1960, Pt. 3, p. 7-17.
- Foose, R. M., 1958, Structural features of the perimeter of the Beartooth Mountains: Billings Geol. Soc. Guidebook, 9th Ann. Field Conf., p. 31-35.
- Frarey, M. J., 1950a, Ile-à-la-Crosse map-area, Saskatchewan: Canada Geol. Survey Paper 50-25, 10 p.
- 1950b, Crowduck Bay, Manitoba: Canada Geol. Survey Map 987A.
- Fraser, J. A., 1960, Crackingstone, Saskatchewan: Canada Geol. Survey Map 1095A.
- Frye, J. K., 1959, Petrography of the ancient granites of the Minnesota-Ontario boundary region: unpublished M. S. thesis, Univ. Minnesota.
- Furnival, G. M., 1941a, Stony Rapids, northern Saskatchewan: Canada Geol. Survey Map 659A.
- 1941b, Porcupine River, northern Saskatchewan: Canada Geol. Survey Map 658A.
- Fyfe, W. S., Turner, F. J., and Verhoogen, J., 1958, Metamorphic reactions and metamorphic facies: Geol. Soc. America Mem. 73, 259 p.
- Fyson, W. K., 1961, Deadwood and Winnipeg stratigraphy in south-western Saskatchewan: Saskatchewan Dept. Mineral Resources Rept. 64, 37 p.
- Gadd, N. R., 1950, Brochet, Manitoba: Canada Geol. Survey Map 1001A.
- Garland, G. D., and Bower, M. E., 1959, Aeromagnetic anomalies in north-eastern Alberta: Oilweek, June 19, p. 32-40.
- Garland, G. D., and Burwash, R. A., 1959, Geophysical and petrological study of Precambrian of central Alberta, Canada: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 4, p. 790-806.
- Gast, P. W., 1961, The rubidium-strontium method: Annals New York Acad. Sci., v. 91, art. 2, p. 181-184.
- Gast, P. W., Kulp, J. L., and Long, L. E., 1958, Absolute ages of early Precambrian rocks in the Bighorn basin of Wyoming and Montana, and southeastern Manitoba: Am. Geophys. Union Trans., v. 39, no. 2, p. 322-334.
- Giletti, B. J., and Gast, P. W., 1961, Absolute age of Pre-Cambrian rocks in Wyoming and Montana: Annals New York Acad. Sci., v. 91, art. 2, p. 454-458.
- Gill, J. C., 1951a, Geology of the Waskaiowaka Lake area, Manitoba: Manitoba Dept. Mines and Nat. Resources, Mines Branch Pub. 50-5, 41 p.

- Gill, J. C., 1951b, Geology of the Mystery Lake area, Manitoba: Manitoba Dept. Mines and Nat. Resources, Mines Branch Pub. 50-4, 19 p.
- Gill, J. E., 1948, The Canadian Precambrian shield, in Structural Geology of Canadian Ore Deposits: Canadian Inst. Mining Metall., p. 20-48.
- 1949, Natural divisions of the Canadian shield: Royal Soc. Canada Trans., v. 43, ser. 3, p. 61-69.
- Gilles, V. A., 1952, Notes on early investigation of the Glendive-Baker or Cedar Creek antilcline: Billings Geol. Soc. Guidebook, 3rd Ann. Field Conf., p. 17-28.
- Godfrey, J. D., 1961, Geology of the Andrew Lake, north district: Alberta Research Council, Prelim. Rept. 58-3, 32 p.
- Godfrey, J. D., and Baadsgaard, H., 1962, Structural pattern of the Precambrian shield in northeastern Alberta, and mica age-dates from the Andrew Lake district: Royal Soc. Canada Spec. Pub. 3, in press.
- Goldich, S. S., Baadsgaard, H., and Nier, A. O., 1957, Investigations in A^{40}/K^{40} dating: Am. Geophys. Union Trans., v. 38, no. 4, p. 547-551.
- Goldich, S. S., Nier, A. O., Baadsgaard, H., Hoffman, J. H., and Krueger, H. W., 1961, The Precambrian geology and geochronology of Minnesota: Minnesota Geol. Survey Bull. 41, 193 p.
- Goodman, A. J., 1954, Tectonics of east side of Cordillera in western Canada, in Western Canada Sedimentary Basin (Rutherford volume): Tulsa, Am. Assoc. Petroleum Geologists, p. 341-354.
- Grout, F. F., 1932, Petrography and Petrology: New York, McGraw-Hill, 522 p.
- Haites, T. B., 1959, Avonlea and its significance: Alberta Soc. Petroleum Geologists Jour., v. 7, no. 8, p. 167-176.
- 1960, Transcurrent faults in western Canada: Alberta Soc. Petroleum Geologists Jour., v. 8, no. 2, p. 33-37.
- Hale, W. E., 1954a, Black Bay map-area, Saskatchewan: Canada Geol. Survey Paper 53-15.
- 1954b, Gulo Lake map-area, Saskatchewan: Canada Geol. Survey Paper 54-6.
- 1955, Forcie Lake map-area, Saskatchewan: Canada Geol. Survey Paper 55-4.
- Harrison, J. M., 1949a, Kississing, Manitoba: Canada Geol. Survey Map 970A.
- 1949b, Geology and mineral deposits of File-Tramping Lakes area, Manitoba: Canada Geol. Survey Mem. 250, 92 p.
- 1951a, Precambrian correlation and nomenclature, and problems of the Kisseynew gneisses, in Manitoba: Canada Geol. Survey Bull. 25, 53 p.
- 1951b, Sipiwesk, Manitoba: Canada Geol. Survey Map 51-3.
- Hart, S. R., 1961a, The use of hornblendes and pyroxenes for K-Ar dating: Jour. Geophys. Research, v. 66, no. 9, p. 2995-3001.

- Hart, S. R., 1961b, Mineral ages and metamorphism: *Annals New York Acad. Sci.*, v. 91, art. 2, p. 192-197.
- Hayden, R. J., and Wehrenberg, J. P., 1960, $A^{40}\text{-K}^{40}$ dating of igneous and metamorphic rocks in western Montana: *Jour. Geology*, v. 69, no. 1, p. 94-97.
- Henderson, J. F., 1939a, Taltson Lake, District of Mackenzie: *Canada Geol. Survey Map* 525A.
- 1939b, Nonacho Lake, District of Mackenzie: *Canada Geol. Survey Map* 526A.
- Henderson, J. F., Norman, G. W. H., and Downie, D. L., 1936, Granville Lake sheet (east half), Manitoba: *Canada Geol. Survey Map* 344A.
- Hess, H. H., 1960, Stillwater igneous complex, Montana: *Geol. Soc. America Mem.* 80, 230 p.
- Hoadley, J. W., 1955, Abitau Lake, District of Mackenzie: *Canada Geol. Survey Paper* 55-10.
- Horwood, H. C., 1935, A pre-Keewatin (?) tonalite: *Royal Soc. Canada Trans.* v. 29, ser. 3, sec. 4, p. 139-147.
- Hunt, G. H., 1961, The Purcell eruptive rocks: unpublished Ph.D. thesis, Univ. Alberta, 139 p.
- Hurley, P. M., and others, 1961, Variations in isotopic abundances of strontium, calcium, and argon and related topics: *Ninth Ann. Progress Rept. 1961*, NYO-3942, U. S. Atomic Energy Comm., 285 p.
- Innes, M. J. S., 1960a, Gravity and isotasy in northern Ontario and Manitoba: *Canada Dominion Observatories Pub.*, v. 21, no. 6, p. 263-338.
- 1960b, Gravity anomaly map of Canada: *Canada Dominion Observatories Pub.*
- Jacobs, J. A., Russell, R. D., and Wilson, J. T., 1959, *Physics and Geology*: New York, McGraw-Hill, 423 p.
- Johannsen, A., 1939, *Petrography of Igneous Rocks*: Chicago, Univ. Chicago Press, v. 1, chap. 14.
- Johnston, A. W., 1938a, Norway House sheet (west half), Manitoba: *Canada Geol. Survey Map* 424A.
- 1938b, Norway House sheet (east half), Manitoba: *Canada Geol. Survey Map* 423A.
- 1938c, Berens River sheet (west half), Manitoba: *Canada Geol. Survey Map* 427A.
- 1938d, Berens River sheet (east half), Manitoba: *Canada Geol. Survey Map* 426A.
- 1938e, Deer Lake (west half), Manitoba-Ontario: *Canada Geol. Survey Map* 425A.
- 1938F, Carrol Lake sheet (west half), Manitoba-Ontario: *Canada Geol. Survey Map* 428A.

- Johnston, A. W., 1938g, Hecla sheet (east half), Manitoba: Canada Geol. Survey Map 429A.
- Johnston, F. J., 1960, The geology of the Tantato Lake area (Astrolabe Lake, east half), Saskatchewan: Saskatchewan Dept. Mineral Resources Rept. 44, 32 p.
- 1961, The geology of the Astrolabe Lake area (west half), Saskatchewan: Saskatchewan Dept. Mineral Resources Rept. 59, 26 p.
- Kalliokoski, J., 1952, Weldon Bay map-area, Manitoba: Canada Geol. Survey Mem. 270, 80 p.
- 1953, Interpretations of the structural geology of the Sherridon-Flin Flon region, Manitoba: Canada Geol. Survey Bull. 25, 18 p.
- Kamen-Kaye, M., 1953, The tectonic patterns of southwestern Saskatchewan, Canada: Billings Geol. Soc. Guidebook, 4th Ann. Field Conf., p. 118-122.
- Kirkland, S. J. T., 1957, The geology of the Manawan Lake area (north half), Saskatchewan: Saskatchewan Dept. Mineral Resources Rept. 27, 22 p.
- 1958, The geology of the Deschambault Lake area (east half), Saskatchewan: Saskatchewan Dept. Mineral Resources Rept. 31, 18 p.
- 1959, The geology of the Brabant Lake area, Saskatchewan: Saskatchewan Dept. Mineral Resources Rept. 33, 33 p.
- Knechtel, M. M., 1959, Stratigraphy of the Little Rocky Mountains and encircling foothills, Montana: U. S. Geol. Survey Bull. 1072N, p. 723-752.
- Kornfeld, J. A., 1954, Seismic problems in Williston basin: Oil and Gas Jour. v. 52, no. 50, pt. 4, p. 196-200.
- Koster, F., 1961, The geology of the Thainka Lake area (west half), Saskatchewan: Saskatchewan Dept. Mineral Resources Rept. 61, 28 p.
- Kretz, R., 1959, Northern Indian Lake, Manitoba: Canada Geol. Survey Map 2-1959.
- Kulp, J. L., and Basset, W. H., 1961, The base-exchange effects on potassium-argon and rubidium-strontium isotopic ages: Annals New York Acad. Sci. v. 91, art. 2, p. 225-226.
- Kupsch, W. O., 1958, Surface structures in southern Saskatchewan, in Second Williston Basin Symposium, Saskatchewan Geol. Soc. and North Dakota Geol. Soc., p. 118-126.
- Kupsch, W. O., and Wild, J., 1958, Lineaments in Avonlea area, Saskatchewan: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 1, p. 127-134.
- Lang, A. H., 1961, A preliminary study of Canadian metallogenic provinces: Canada Geol. Survey Paper 60-33, 54 p.
- Lawson, A. C., 1913, The Archean geology of Rainy Lake restudied: Canada Geol. Survey Mem. 40, 115 p.

- Levorsen, A. I., 1956, *Geology of Petroleum*: San Francisco, W. H. Freeman, 703 p.
- Link, T. A., 1958, The Williston basin is large and deep, in Second Williston Basin Symposium, Saskatchewan Geol. Soc. and North Dakota Geol. Soc., p. 6-7.
- Lobeck, A. K., 1948, *Physiographic provinces of North America*: New York, The Geographical Press, Columbia Univ.
- Lord, C. S., 1953, Geological notes on the southern District of Keewatin, Northwest Territories: Canada Geol. Survey Paper 53-22, 11 p.
- Lowdon, J. A., 1960, Age determinations by the Geological Survey of Canada, report 1, isotopic ages: Canada Geol. Survey Paper 60-17, 51 p.
- 1961, Age determinations by the Geological Survey of Canada, report 2, isotopic ages: Canada Geol. Survey Paper 61-17, 127 p.
- McCabe, H. R., 1959, Mississippian stratigraphy of Manitoba: Manitoba Dept. Mines and Nat. Resources, Mines Branch Pub. 58-1, 99 p.
- McGlynn, J. C., 1959, Elbow-Heming Lakes area, Manitoba: Canada Geol. Survey Mem. 305, 72 p.
- McLarty, D. M. E., 1936a, Lac la-Ronge (east half), Saskatchewan: Canada Geol. Survey Map 358A.
- 1936b, Lac la-Ronge (west half), Saskatchewan: Canada Geol. Survey Map 357A.
- McMurchy, R. C., 1938a, Foster Lake sheet (east half), northern Saskatchewan: Canada Geol. Survey Map 433A.
- 1938b, Foster Lake sheet (west half), northern Saskatchewan: Canada Geol. Survey Map 434A.
- Macauley, G., 1958, Geologic bibliography: Alberta Soc. Petroleum Geologists Jour., v. 6, Peace River symposium no., no. 3, p. 82-86.
- Mawdsley, J. B., 1957a, The geology of the Charlebois Lake area, northern Saskatchewan: Saskatchewan Dept. Mineral Resources Rept. 24.
- 1957b, The geology of the Middle Foster Lake area, northern Saskatchewan: Saskatchewan Dept. Mineral Resources Rept. 26, 45 p.
- Mawdsley, J. B., and Grout, F. F., 1951, The geology of the Stanley map area, northern Saskatchewan: Saskatchewan Dept. Nat. Resources, Precambrian Geology Ser., Rept. 4, 31 p.
- Meek, K. S., Jr., 1958, Precambrian of the Canadian Williston basin, in Second Williston Basin Symposium, Saskatchewan Geol. Soc. and North Dakota Geol. Soc., p. 17-19.
- Miller, M. L., 1949, The geology of the Windrum Lake area, Saskatchewan: Saskatchewan Dept. Nat. Resources, Precambrian Geology Ser., Rept. 3, 24 p.

- Miller, A. H., and Innes, M. J. S., 1952, Gravity anomaly maps for the provinces of Saskatchewan, Manitoba, and Alberta: Canada Dominion Observatory Pub.
- Milligan, G. C., 1952, Geology of the Utik Lake-Bear Lake area, northern Manitoba: Manitoba Dept. Mines and Nat. Resources Pub. 51-4, 25 p.
- 1960, Geology of the Lynn Lake district: Manitoba Dept. Mines and Nat. Resources, Mines Branch Pub. 57-1, 317 p.
- Milne, W. G., and Nickoloff, G. D., 1955, Virden-Roselea shows promise of Manitoba: Petroleum Eng., Feb., p. B-81 to B-90.
- Mollard, J. D., 1958, Photogeophysics--its application in petroleum exploration over glaciated plains of western Canada, in Second Williston Basin Symposium, Saskatchewan Geol. Soc. and North Dakota Geol. Soc., p. 109-117.
- Money, P. L., 1961, The geology of the Barnett Lake area (west half), Saskatchewan: Saskatchewan Dept. Mineral Resources Rept. 60, 27 p.
- Moody, J. D., and Hill, M. J., 1956, Wrench-fault tectonics: Geol. Soc. America Bull., v. 67, no. 9, p. 1207-1246.
- Moore, J. M., Jr., Hart, S. R., Barnett, C. C., and Hurley, P. M., 1960, Potassium-argon ages in northern Manitoba: Geol. Soc. America Bull. v. 71, no. 2, p. 225-230.
- Moorhouse, W. W., 1959, The study of Rocks in Thin Section: New York, Harper and Brothers, 514 p.
- Morris, A., 1960, The geology of the Trout Lake area (east half), Saskatchewan: Saskatchewan Dept. Mineral Resources Rept. 42, 22 p.
- 1961, The geology of the Settee Lake area (west half), Saskatchewan: Saskatchewan Dept. Mineral Resources Rept. 55, 27p.
- Moss, R. G., 1936, Buried pre-Cambrian surface in the United States: Geol. Soc. America Bull., v. 47, no. 6, p. 935-966.
- Mulligan, R., 1956, Hill Island Lake (east half), District of Mackenzie: Canada Geol. Survey Paper 55-25.
- 1957, Split Lake, Manitoba: Canada Geol. Survey Map 10-1956.
- National Research Council, 1958, Rock-color chart: Washington, D. C.
- Noble, J. A., 1952, Structural features of the Black Hills and adjacent areas developed since Precambrian times: Billings Geol. Soc. Guide-book, 3rd Ann. Field Conf., p. 31-37.
- Osterwald, F. W., 1956, Relation of tectonic elements in Precambrian rocks to uranium deposits in the Cordilleran foreland of the western United States: U. S. Geol. Survey Prof. Paper 300, p. 329-335.
- Osterwald, F. W., and Dean, B. G., 1961, Relation of uranium deposits to tectonic pattern of the central Cordilleran foreland: U. S. Geol. Survey Bull., 1087-I, p. 337-390.

- Padgham, W. A., 1960, The geology of the Otter Lake area (west half),
Saskatchewan: Saskatchewan Dept. Mineral Resources Rept. 41, 34 p.
- Pearson, W. J., and Froese, E., 1959, The geology of the Forbes Lake area,
Saskatchewan: Saskatchewan Dept. Mineral Resources Rept. 34, 28 p.
- Pinson, W. H., Jr., 1961, The potassium-argon method, the problem of potassium
analysis: Annals New York Acad. Sci., v. 91, art. 2, p. 221-224.
- Poldervaart, A., and Bentley, R. D., 1958, Precambrian and later evolution
of the Beartooth Mountains, Montana and Wyoming: Billings Geol. Soc.
Guidebook, 9th Ann. Field Conf., p. 7-15.
- Porter, J. W., and Fuller, J. G. C. M., 1958, Succession of lower Paleozoic
rocks in the northern part of the Williston basin, in Second Williston
Basin Symposium, Saskatchewan Geol. Soc. and North Dakota Geol. Soc.,
p. 33-39.
- Pye, W. D., 1958, Habitat of oil in northern Great Plains and Rocky Mountains,
in Habitat of Oil, Am. Assoc. Petroleum Geologists, p. 178-224.
- Pyke, M. W., 1960, The geology of the Wapus Bay area (east half), Saskatchewan:
Saskatchewan Dept. Mineral Resources Rept. 40, 32 p.
- 1961, The geology of the Attitti Lake area (west half), Saskatchewan:
Saskatchewan Dept. Mineral Resources Rept. 54, 32 p.
- Quinn, H. A., 1955, Nelson House, Manitoba: Canada Geol. Survey Map 54-13
- 1956, Knee Lake, Manitoba: Canada Geol. Survey Map 55-8.
- 1960a, Big Sand Lake, Manitoba: Canada Geol. Survey Map 45-1959.
- 1960b, Island Lake, Manitoba-Ontario: Canada Geol. Survey Map 26-1960.
- 1961, Kettle Rapids, Manitoba: Canada Geol. Survey Map 9-1961.
- Rankama, K., 1954, Isotope Geology: New York, Pergamon Press, 535 p.
- Rankama, K., and Sahama, Th. G., 1950, Geochemistry: Chicago, Univ. Chicago
Press, 912 p.
- Reeves, F., 1953, Bearpaw thrust faulted area: Billings Geol. Soc. Guidebook,
4th Ann. Field Conf., p. 114-117.
- Rice, H. M. A., 1951, Mudjatic-Geike, Saskatchewan: Canada Geol. Survey
Map 1007A.
- 1953, Reindeer Lake, Saskatchewan-Manitoba: Canada Geol. Survey
Map 1016A.
- Riley, G. C., 1960, Fort Fitzgerald, Alberta: Canada Geol. Survey Map 12-
1960.
- Robertson, D. S., 1953, Batty Lake map-area, Manitoba: Canada Geol. Survey
Mem. 271, 55 p.

- Robinson, S. C., 1955, Mineralogy of uranium deposits, Goldfields, Saskatchewan: Canada Geol. Survey Bull. 31, 128 p.
- Ross, C. P., 1933, Ore deposits in Idaho in relation to structural and historical geology, in Ore Deposits of the Western United States (Lindgren volume): New York, Am. Inst. Mining Metall. Engineers, p. 265-271.
- Ross, C. P., Andrews, D. A., and Witkind, I. J., 1955, Geologic map of Montana: U. S. Geol. Survey.
- Sawatzky, H. B., 1959a, Composite seismic map of Saskatchewan: Saskatchewan Dept. Mineral Resources, 2 maps.
- 1959b, Regional gravity map of Saskatchewan: Saskatchewan Dept. Mineral Resources, 2 maps.
- Sawatzky, H. B., and Agarwal, R. B., 1958, Regional magnetic map of Saskatchewan: Saskatchewan Dept. Mineral Resources, 3 maps.
- Sawatzky, H. B., Agarwal, R. B., and Wilson, W., 1959, Structure test holes confirm post-Paleozoic relief as indicated by the seismograph in the Avonlea area, Saskatchewan: Alberta Soc. Petroleum Geologists Jour., v. 7, no. 4, p. 82-90.
- 1960, Helium prospects in southwest Saskatchewan: Saskatchewan Dept. Mineral Resources Rept. 49, 26 p.
- Schroth, H. A., 1953, Bowdoin dome, Montana: Billings Geol. Soc. Guidebook, 4th Ann. Field Conf., p. 137-142.
- Sikabonyi, L. A., 1957, Tectonic trends in the prairie region of Canada: Alberta Soc. Petroleum Geologists Jour., v. 5, no. 2, p. 23-28.
- Sikabonyi, L. A., and Rodgers, W. J., 1959, Paleozoic tectonics and sedimentation in the northern half of the west Canadian basin: Alberta Soc. Petroleum Geologists Jour., v. 7, no. 9, p. 193-216.
- Sloss, L. L., 1950, Paleozoic sedimentation in Montana area: Am. Assoc. Petroleum Geologists Bull., v. 34, no. 3, p. 423-451.
- Sonnenberg, F. P., 1956, Tectonic patterns of central Montana: Billings Geol. Soc. Guidebook, 7th Ann. Field Conf., p. 82-85.
- Spencer, E. W., 1958, Structural trend in the Beartooth Mountains, Montana and Wyoming: Billings Geol. Soc. Guidebook, 9th Ann Field Conf., p. 16-23.
- Sproule, J. C., 1941, Weitzel Lake, northern Saskatchewan: Canada Geol. Survey Map 576A.
- 1957, Clastic reservoirs on Precambrian surface in North America: Am. Assoc. Petroleum Geologists Bull., v. 41, p. 848-860.
- Sproule, J. C., and Downie, D. L., 1941, Brustad River, northern Saskatchewan: Canada Geol. Survey Map 577A.
- Stanton, M. S., 1947, Tramping Lake, Manitoba: Canada Geol. Survey Map 906A.

- Steece, F. J., 1961, Preliminary map of the Precambrian surface of South Dakota: South Dakota Geol. Survey, Mineral Resources Map 2.
- Stockwell, C. H., 1938, Rice Lake-Gold Lake area, southeastern Manitoba: Canada Geol. Survey Mem. 210, 79 p.
- 1945a, Rice Lake, Manitoba: Canada Geol. Survey Map 810A.
- 1945b, Gem Lake, Manitoba: Canada Geol. Survey Map 811A.
- 1946, Flin Flon-Mandy area, Manitoba and Saskatchewan: Canada Geol. Survey Paper 46-14.
- 1961, Structural provinces, orogenies, and time classification of rocks of the Canadian Precambrian shield: Canada Geol. Survey Paper 61-17, ed. J. A. Lowdon, p. 108-118.
- Stockwell, C. H., and Lord, C. S., 1939, Halfway Lake-Beresford Lake area, Manitoba: Canada Geol. Survey Mem. 219, 67 p.
- Stose, G. W., 1960, Geologic map of the United States: U. S. Geol. Survey.
- Tanton, T. L., 1941a, Schist Lake, Manitoba: Canada Geol. Survey Map 633A.
- 1941b, Flin Flon, Manitoba: Canada Geol. Survey Map 632A.
- Taylor, F. C., 1956, Hill Island Lake (east half), District of Mackenzie: Canada Geol. Survey Paper 55-16.
- 1957, Snowbird Lake, District of Mackenzie: Canada Geol. Survey Map 7-1956.
- 1958a, Pelican Narrows, Saskatchewan: Canada Geol. Survey Map 1-1958.
- 1958b, Shethanei Lake, Manitoba: Canada Geol. Survey Paper 58-7.
- 1959a, Wholdaia Lake, District of Mackenzie: Canada Geol. Survey Map 9-1959.
- 1959b, Penylan Lake-Firedrake Lake, District of Mackenzie: Canada Geol. Survey Map 8-1959.
- 1959c, Nonacho Lake, District of Mackenzie: Canada Geol. Survey Map 10-1959
- Tilton, G. R., Wetherill, G. W., Davis, G. L., and Hopson, C. A., 1958, Ages of minerals from the Baltimore gneiss near Baltimore, Maryland: Geol. Soc. America Bull., v. 69, p. 1469-1474.
- Thom, W. T., Jr., 1955, Wedge uplifts and their tectonic significance, in Crust of the Earth, ed. Arie Poldervaart: Geol. Soc. America Spec. Paper 62, p. 369-376.
- 1957, Tectonic relationships, evolutionary history, and mechanics or origin of the Crazy Mountain basin, Montana: Billings Geol. Soc. Guidebook, 8th Ann. Field Conf., p. 9-21.
- 1959, Tectonic sketch map of North America: Red Lodge, Montana, Yellowstone-Bighorn Assoc.

- Tremblay, L. P., 1960, Phelps Lake, Saskatchewan: Canada Geol. Survey Map 5-1960.
- 1961, Firebag River area, Alberta and Saskatchewan: Canada Geol. Survey Map 16-1961.
- Tullis, E. L., 1952, Igneous and metamorphic rocks of the Black Hills and the Williston basin: Billings Geol. Soc. Guidebook, 3rd Ann. Field Conf., p. 38-41.
- Tuttle, O. F., and Bowen, N. L., 1958, Origin of granite in light of experimental studies in the system $\text{NaAlSi}_3\text{O}_8$ - KAlSi_3O_8 - SiO_2 - H_2O : Geol. Soc. America Mem. 74, 153 p.
- Van Hees, H., 1958, The Meadow Lake escarpment--its regional significance to lower Paleozoic stratigraphy, in Second Williston Basin Symposium: Saskatchewan Geol. Soc. and North Dakota Geol. Soc., p. 70-78.
- Watanabe, R. Y., 1961, Geology of the Waugh Lake metasedimentary complex, northeastern Alberta: unpublished M.Sc. thesis, Univ. Alberta, 89 p.
- Webb, J. B., 1954, Geological history of plains of western Canada, in Western Canada Sedimentary Basin (Rutherford volume): Tulsa, Am. Assoc. Petroleum Geologists, p. 3-28.
- Weed, W. H., 1899a, Description of the Fort Benton quadrangle (Montana): U. S. Geol. Survey Geol. Atlas Folio 55.
- 1899b, Description of the Little Belt Mountains quadrangle (Montana): U. S. Geol. Survey Geol. Atlas Folio 56.
- Weeks, L. J., 1941a, Reindeer Lake, northern Saskatchewan: Canada Geol. Survey Map 595A.
- 1941b, Spalding Lake, northern Saskatchewan: Canada Geol. Survey Map 596A.
- Wetherill, G. W., Kouvo, O., Tilton, G. R., and Gast, P. W., 1962, Age measurements on rocks from Finnish Precambrian: Jour. Geology, v. 7, no. 1, p. 74-88.
- Wilson, J. T., 1941, Fort Smith, District of Mackenzie: Canada Geol. Survey Map 607A.
- 1949a, Some major structures of the Canadian shield: Canadian Inst. Mining Metallurgy Trans., v. 52, p. 231-242.
- 1949b, The origins of continents and Precambrian history: Royal Soc. Canada Trans., v. 43, ser. 3, p. 157-183.
- Wilson, J. T., Russell, R. D., and Farquhar, R. M., 1956, Economic significance of basement subdivision and structures in Canada: Canadian Inst. Mining Metallurgy Trans., v. 59, p. 310-318.
- Wilson, M. E., 1939, The Canadian shield, in Geologie der Erde, Geology of North America I: Berlin.

- Wilson, M. E., 1941, Pre-Cambrian: Geol. Soc. America (Fiftieth Anniversary volume), p. 271-305.
- Wilson, H. D. B., and Brisbin, W. C., 1961, Regional structure of the Thompson-Moak Lake nickel belt: Canadian Mining Metall. Bull., no. 595, p. 815-822.
- Wise, D. U., 1958, The relationship of Precambrian and Laramide structure in the southern Beartooth Mountains, Wyoming: Billings Geol. Soc. Guidebook, 9th Ann. Field Conf., p. 24-30.
- Wisser, E. H., 1959, Cordilleran ore districts in relation to regional structure: Canadian Mining Metall. Bull., p. 34-42.
- Woolard, G. P., 1958, Areas of tectonic activity in the United States as indicated by earthquake epicenters: Am. Geophys. Union Trans., v. 39, no. 6, p. 1135-1150.
- Wright, J. F., 1932, Geology and mineral deposits of a part of southeastern Manitoba: Canada Geol. Survey Mem 169, 150 p.
- 1934a, Oxford House sheet, Manitoba: Canada Geol. Survey Map 305A.
- 1934b, The Pas sheet, Manitoba and Saskatchewan: Canada Geol. Survey Map 268A.
- Wright, G. M., 1952, Reliance, District of Mackenzie: Canada Geol. Survey Paper 51-26.
- 1953, Uhlman Lake, Manitoba: Canada Geol. Survey Map 53-12.
- 1955, Geological notes on central District of Keewatin, Northwest Territories: Canada Geol. Survey Paper 55-17, 17 p.
- 1957, Geological notes on eastern District of Mackenzie, Northwest Territories: Canada Geol. Survey Paper 56-10, 23 p.
- Yardley, D. H., Goldich, S. S., Peterman, Z. E., and Frye, J. K., 1959, Precambrian geology of the Minnesota-Ontario border region (abs.): Geol. Soc. America Bull., v. 70, no. 12, p. 1703.

APPENDIX A

Photomicrographs of Basement and Dated Outcrop Samples

PLATE 1

Basement Igneous Rocks, Southeastern Saskatchewan

- A. Porphyritic granophyric granite (4230). Photograph shows well developed graphic intergrowths of quartz and feldspar, and rounded nature of phenocrysts. Magnification X10. Crossed nicols.
- B. Porphyritic biotite granite (3633). Dark areas in upper and lower parts of photograph are rounded phenocrysts of strained quartz which appear conspicuously blue in hand specimen. Texture of the ground-mass is hypidiomorphic granular. Magnification X10. Crossed nicols.
- C. Chloritized granite (4220). Large grain of microcline is evident in lower half of photograph. Intensely strained quartz is shown above this. Magnification X10. Crossed nicols.
- D. Granite (4229). Bent twin lamellae are visible in plagioclase grain shown in lower right corner of photograph. Magnification X10. Crossed nicols.
- E. Rhyolite or quartz dacite porphyry (3634). Photograph shows euhedral to subhedral phenocrysts in fine-grained groundmass. Magnification X10. Crossed nicols.
- F. Rhyolite porphyry (2182). Phenocrysts of composite quartz, plagioclase, and microcline in fine-grained groundmass. Magnification X10. Crossed nicols.

PLATE I

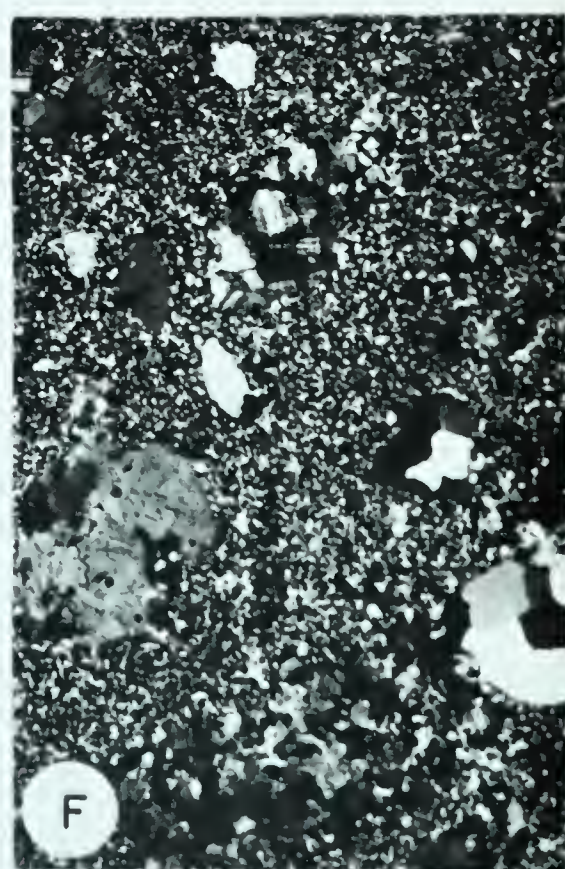
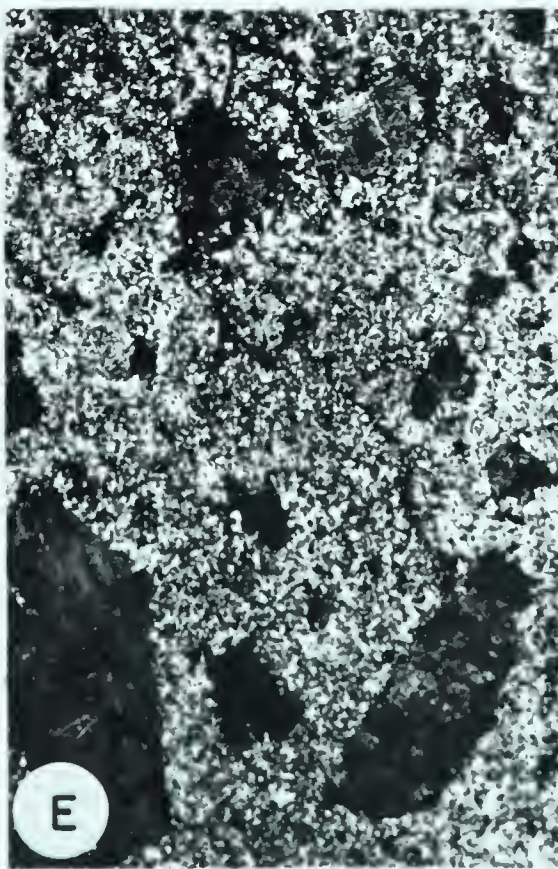
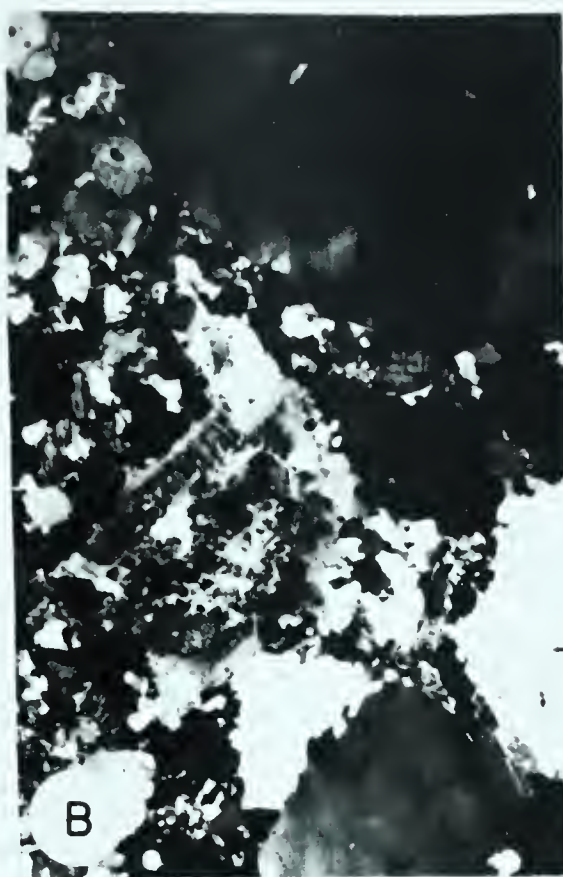
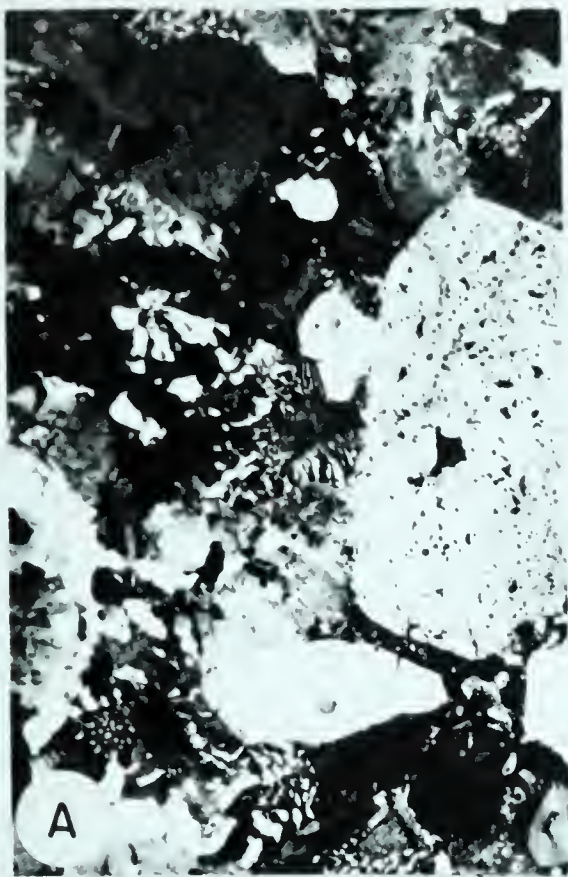


PLATE 2

Basement Igneous Rocks from West-Central Saskatchewan and other Areas

- A. Biotite quartz monzonite (4222). Typical granitic texture is shown. Magnification X10. Crossed nicols.
- B. Biotite granite (2429). Granitic texture formed mainly by quartz, orthoclase, and plagioclase. Magnification X10. Crossed nicols.
- C. Hypersthene quartz monzonite (2428). Partially altered grain of hypersthene is shown in left-center of photograph. Magnification X10. Crossed nicols.
- D. Hornblende-biotite quartz monzonite (2430). Poikilitic hornblende is shown in left of picture. Biotite grains are evident just above this. Magnification X10. Crossed nicols.
- E. Altered biotite granite (4213). Altered plagioclase grain in lower left corner and shattered quartz grain in center of photograph are shown. Carbonate and possibly gypsum fill fractures in quartz. Magnification X10. Crossed nicols.
- F. Microgranite or microgranodiorite (2211). Irregular shaped quartz grains (white) in a finer-grained mosaic of dominantly quartz and feldspar are shown. Magnification X10. Crossed nicols.
- G. Altered granodiorite (4236). Photograph shows severely altered plagioclase (mottled) and fractured quartz. Magnification X10. Crossed nicols.
- H. Biotite quartz monzonite (4219). Partially altered plagioclase (center) bounded by fractured quartz grains are shown. Magnification X10. Crossed nicols.

PLATE 2

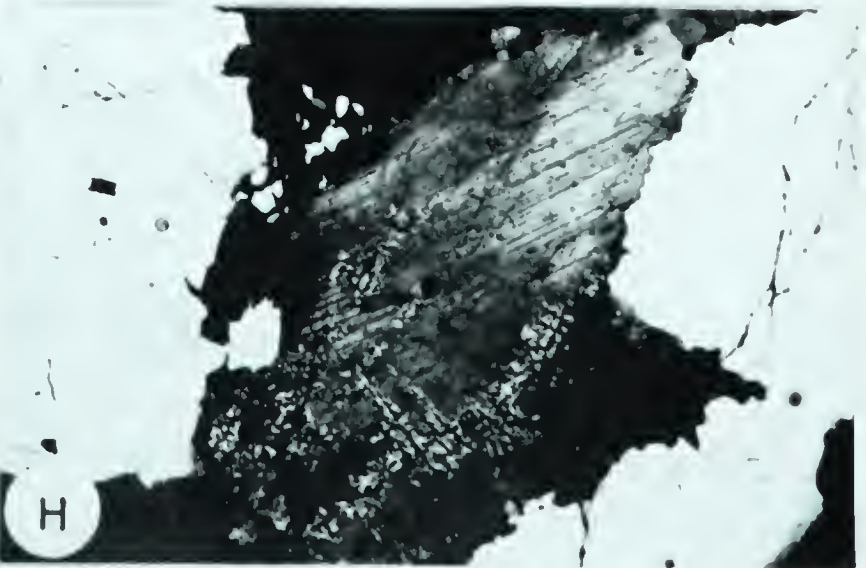
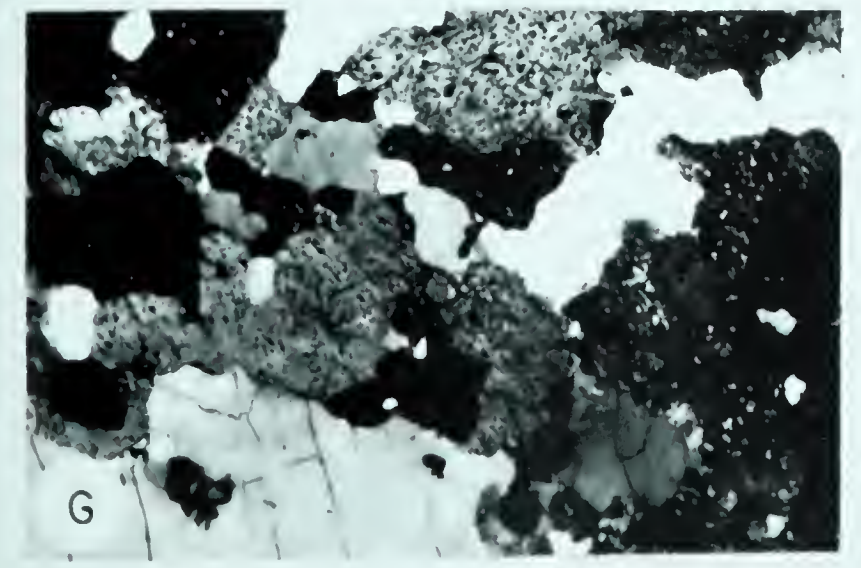
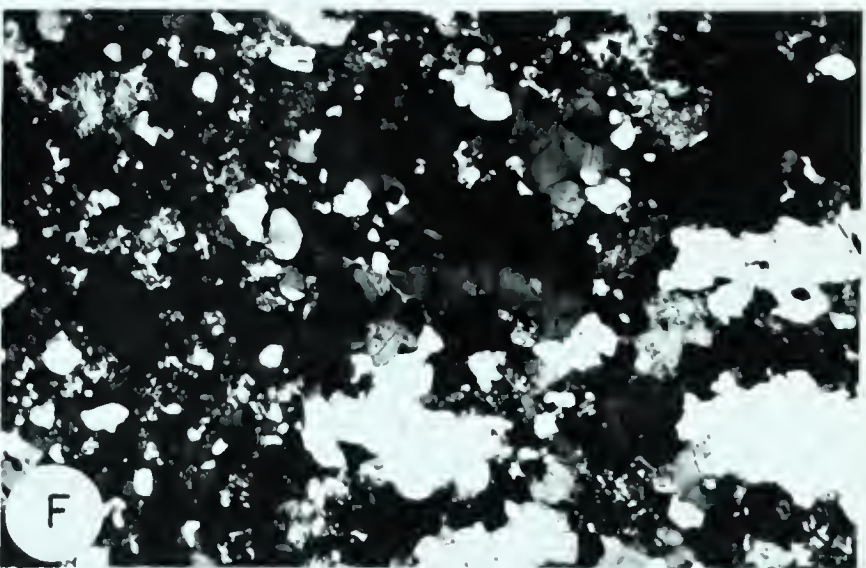
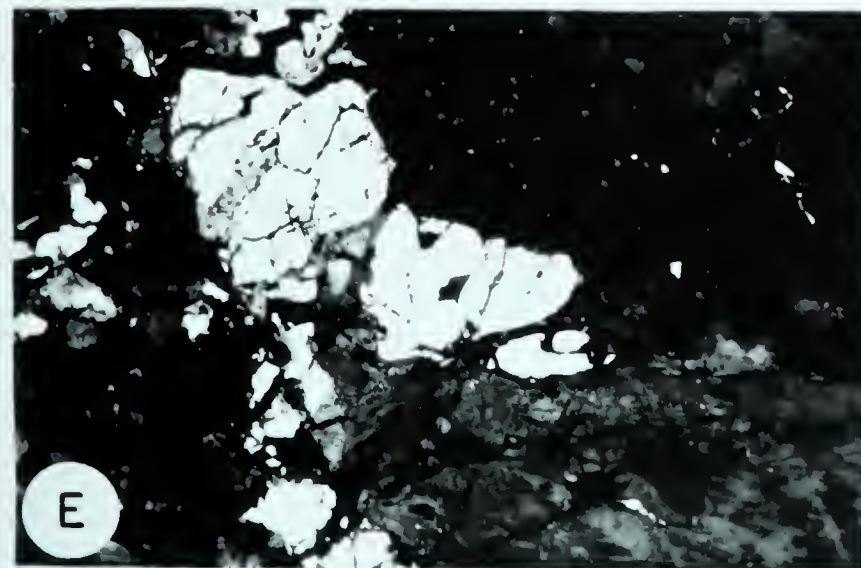
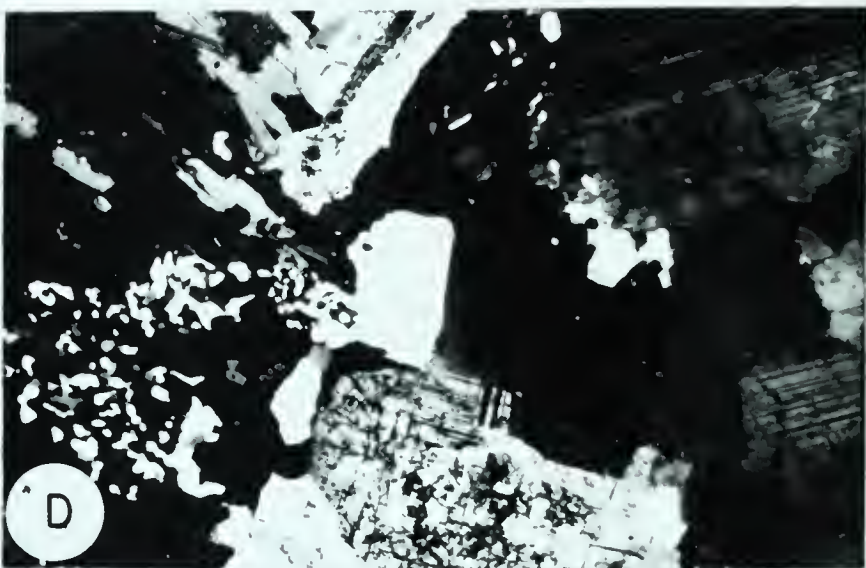
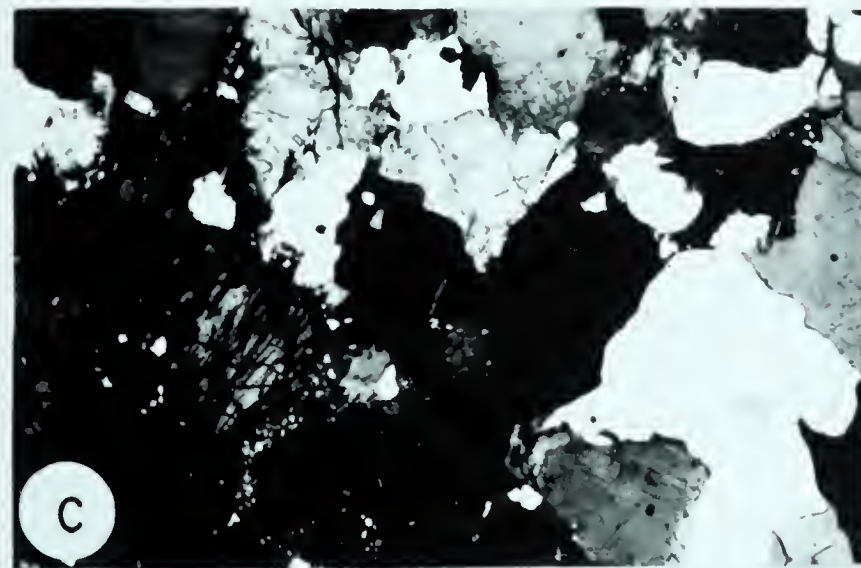


PLATE 3

Basement Igneous and Metamorphic Rocks

- A. Biotite quartz monzonite (4234). Well developed, even-grained, granitic texture is shown. Magnification X10. Crossed nicols.
- B. Altered syenite (4679). Carlsbad twinned lath of orthoclase is shown in center of photograph. Magnification X10. Crossed nicols.
- C. Hornblende-biotite-quartz-feldspar gneiss (4226). Partially altered grain of hornblende is shown in center of photograph. Magnification X10. Crossed nicols.
- D. Biotite quartz monzonite (4680). Photograph shows strained quartz and partially altered plagioclase. Magnification X10. Crossed nicols.
- E. Biotite-quartz-feldspar gneiss (4225a). Foliation imparted by oriented biotite is evident. Magnification X10. Crossed nicols.
- F. Plagioclase amphibolite (4225b). Granoblastic texture is formed by plagioclase (white) and hornblende (dark grey). Magnification X10. Plane polarized light.
- G. Biotite-quartz-feldspar gneiss (4225c). Well twinned microcline and moderately strained quartz are evident. Magnification X10. Crossed nicols.
- H. Biotite-quartz-feldspar gneiss (4225d). Similar to 4225c. Magnification X10. Crossed nicols.

PLATE 3

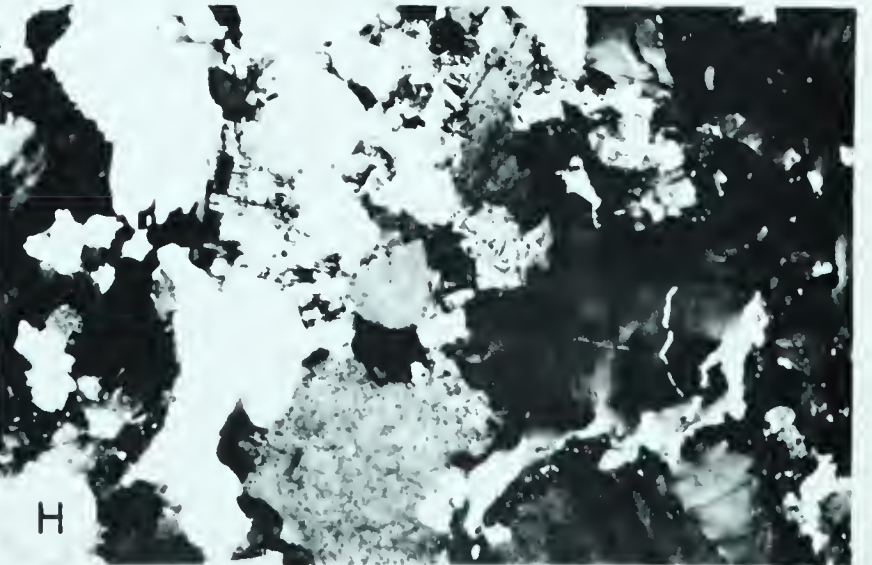
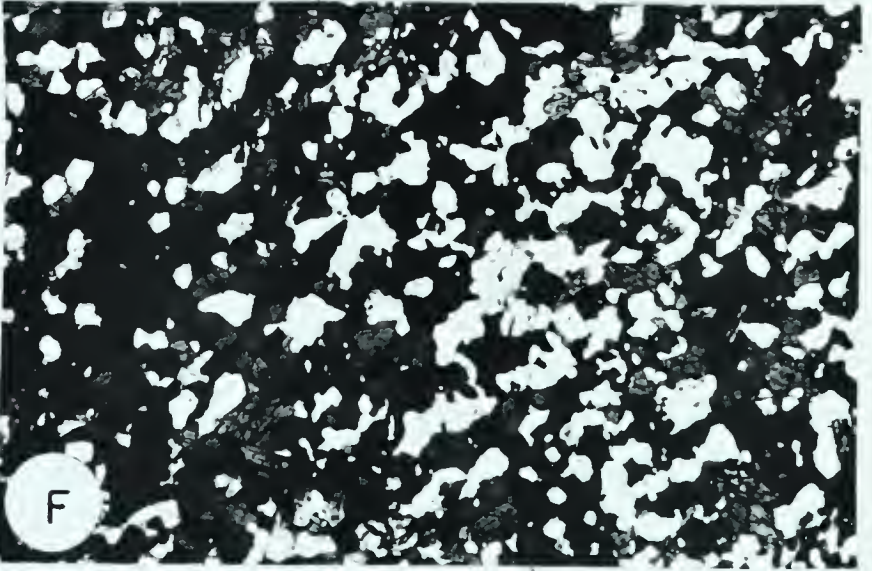
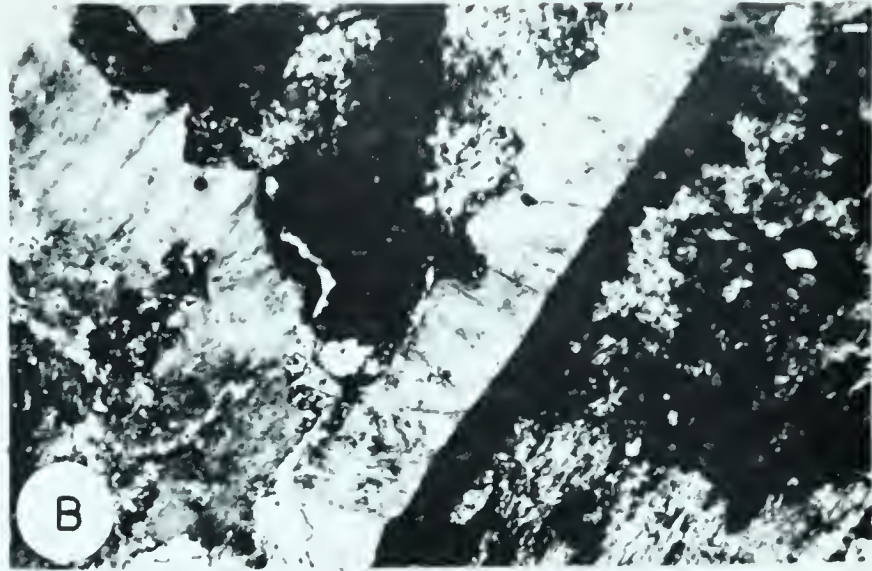


PLATE 4

Basement Metamorphic Rocks

- A. Altered garnet-biotite-quartz-feldspar gneiss (4223). Fractured porphyroblast of garnet is shown in left of photograph. Note small displacements along fractures in quartz. Magnification X10. Plane polarized light.
- B. Altered biotite-quartz gneiss (4227a). Quartz, feldspar, and biotite are shown in a crudely foliated texture. Magnification X10. Crossed nicols.
- C. Feldspar-quartz-mica schist (4224). Dark minerals are mainly biotite grains. Light minerals are quartz, orthoclase, and carbonate. Schistose texture is not well developed in this part of thin section. Magnification X10. Plane polarized light.
- D. Biotite-quartz-feldspar gneiss (4232). Magnification X10. Crossed nicols.
- E. Phyllite and metagreywacke (4228). Greywacke phase is shown in the right three quarters of photograph. Angular to subangular grains of quartz and feldspar are shown in a fine-grained groundmass. Phyllite is dominantly quartz and micaceous minerals. Magnification X10. Crossed nicols.
- F. Iron formation (4484). Photograph shows well developed thin banding of rock. Dark bands are mainly magnetite and biotite and light bands are quartz. Magnification X10. Plane polarized light.
- G. Iron formation (4485b). Concentration of biotite is shown in right one-third of photograph. Remainder is magnetite, quartz, and carbonate. Magnification X10. Plane polarized light.
- H. Carbonate phase of iron formation (4485c). Photograph shows hetero-granular mosaic of carbonate. Straining is evident. Magnification X10. Crossed nicols.

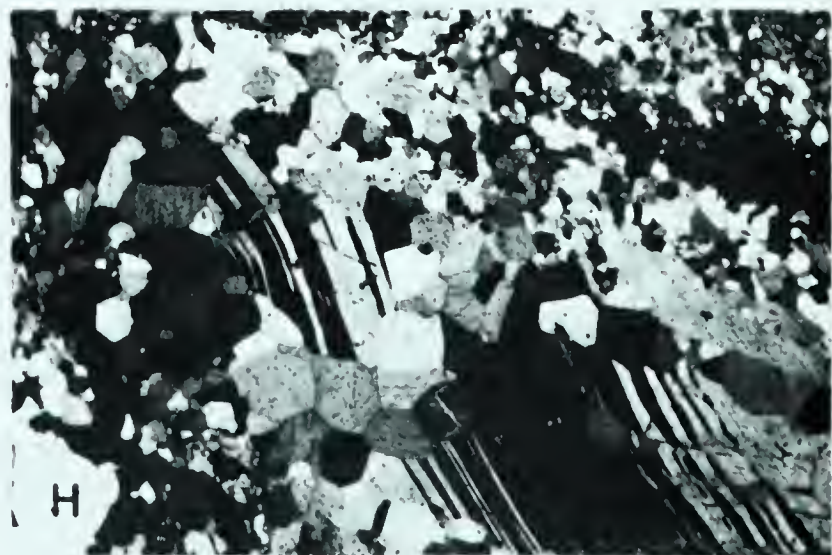
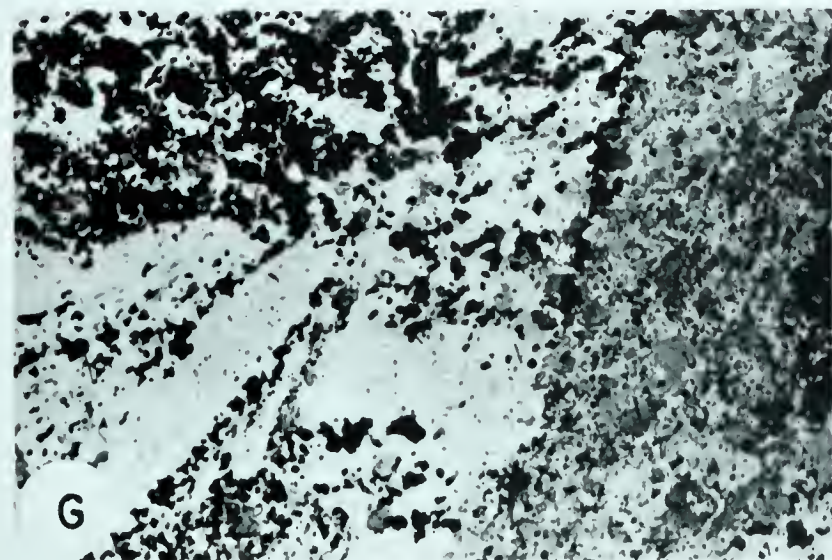
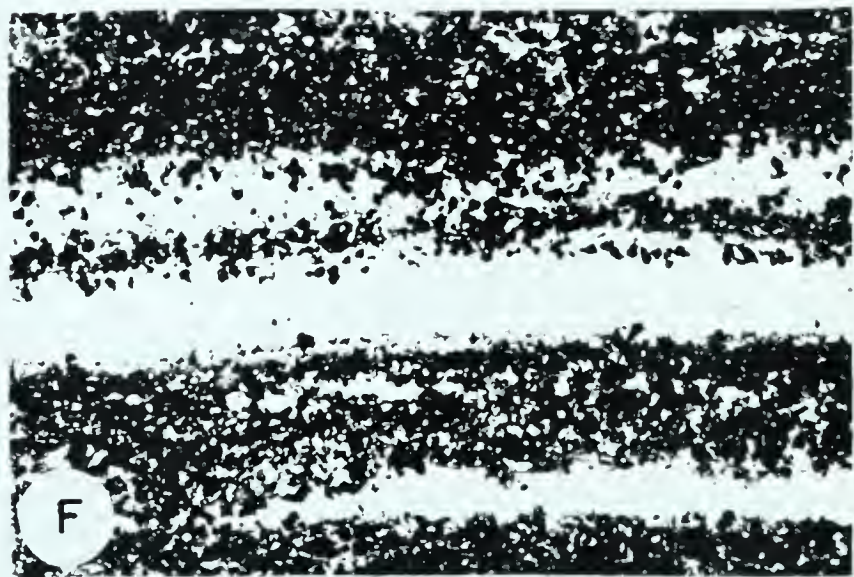
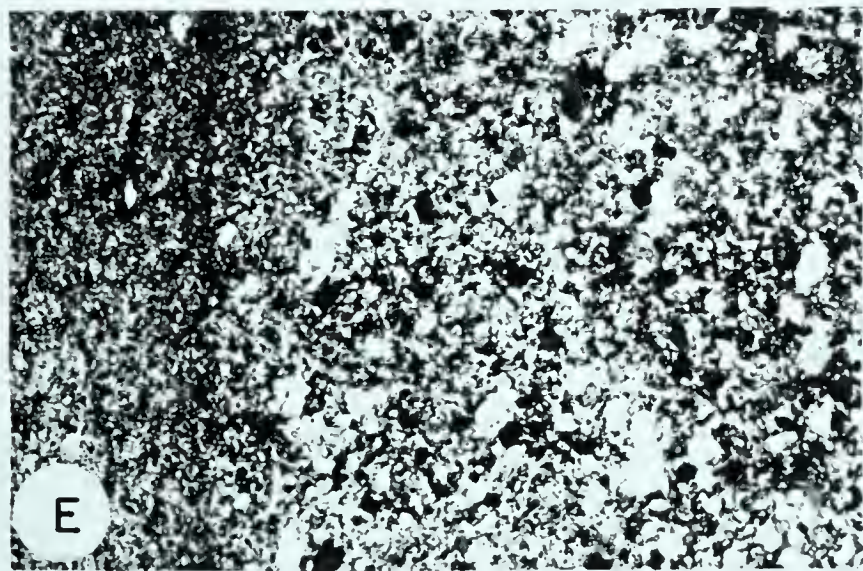
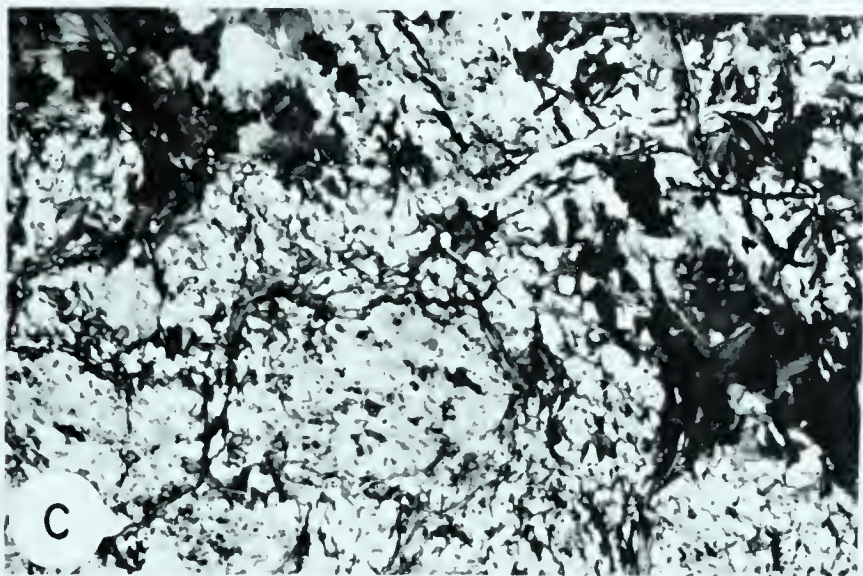
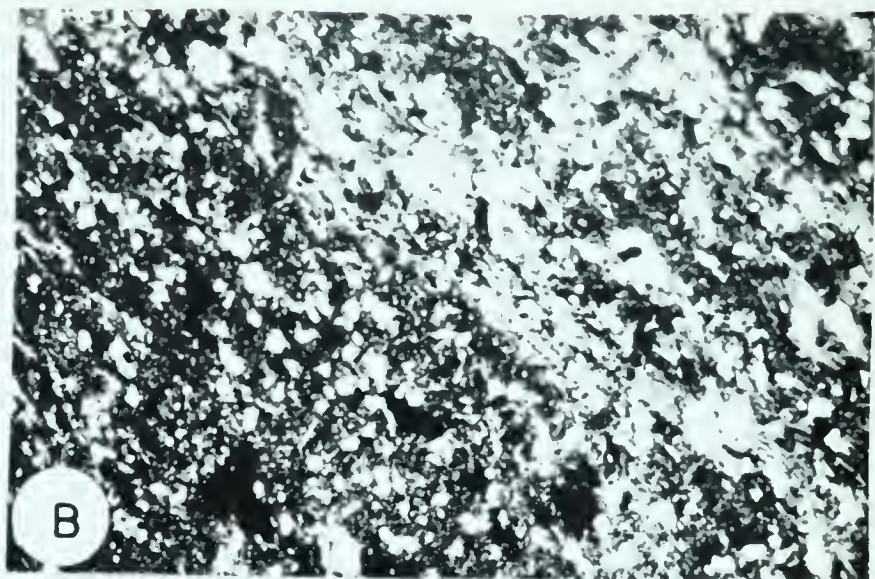
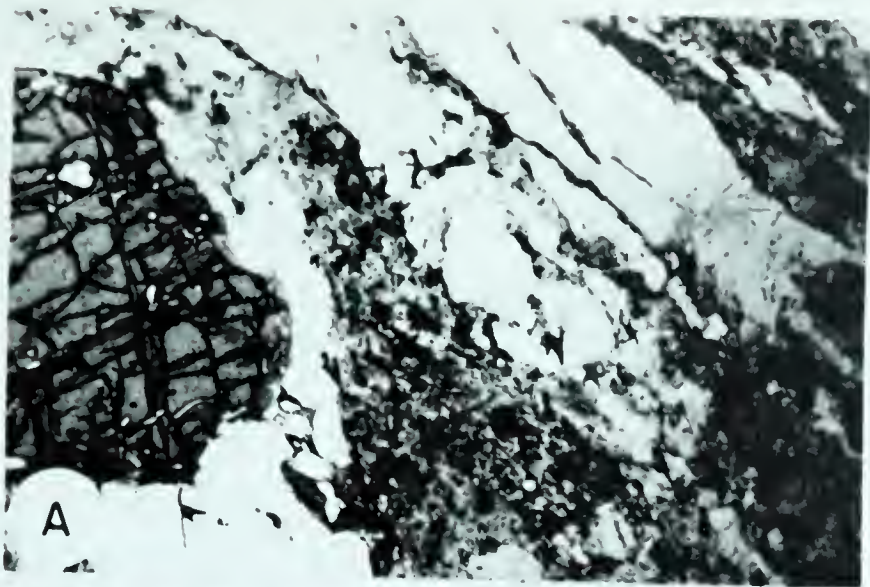


PLATE 5

Basement Metamorphic Rocks

- A. Biotite-quartz-feldspar gneiss (4217). Magnification X10. Crossed nicols.
- B. Muscovite-biotite schist (4215). Well developed lepidoblastic texture is shown. Magnification X10. Crossed nicols.
- C. Cordierite-quartz-biotite schist (4237). Cordierite is shown as partially altered grain (grey) in upper left corner of photograph. Magnification X10. Crossed nicols.
- D. Biotite-quartz-feldspar gneiss (4238). Note the oriented flakes of muscovite in plagioclase grain (lower center) and fine twinning in microcline (upper right corner). Magnification X10. Crossed nicols.
- E. Biotite-quartz-feldspar gneiss (4677). Oriented grains of biotite are shown. Magnification X10. Crossed nicols.
- F. Calcareous quartz-mica schist (4218). Light minerals are mainly quartz and feldspar; dark aggregates are composed of sericite, biotite, and some carbonate. Magnification X10. Crossed nicols.
- G. Chlorite-biotite schist (4231b). Quartz (white) and iron stained biotite (dark grey) are evident in a fine-grained groundmass of indeterminate minerals. Magnification X10. Plane polarized light.
- H. Biotite-hornblende-quartz-andesine gneiss (4231d). Anhedral mosaic of quartz, feldspar, and mafic minerals is shown. Magnification X10. Crossed nicols.

PLATE 5

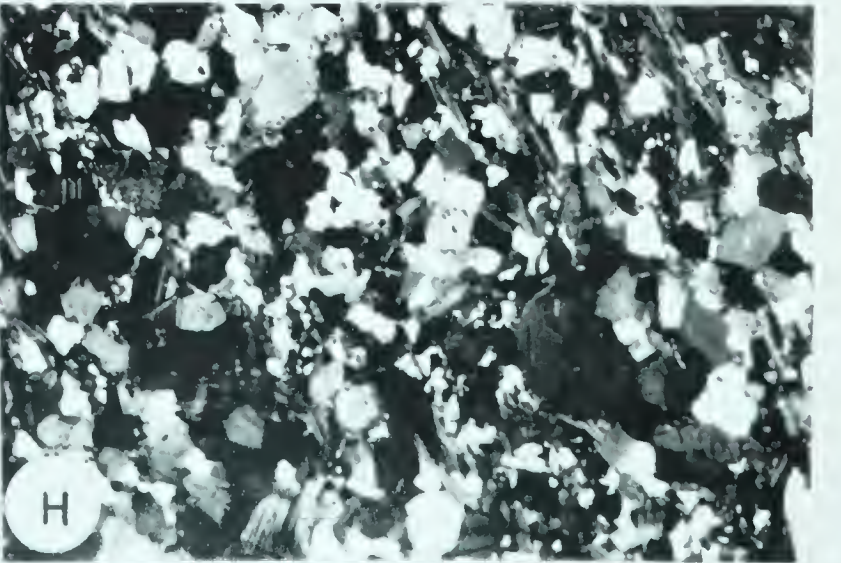
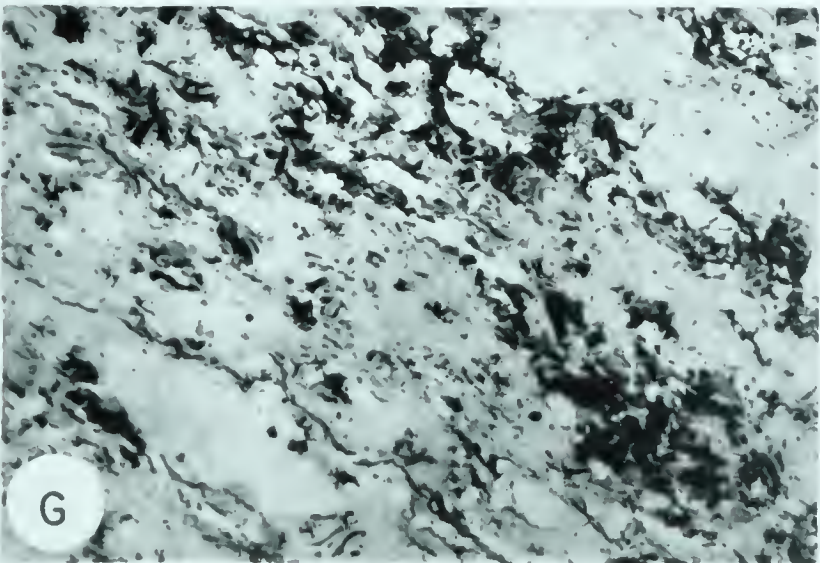
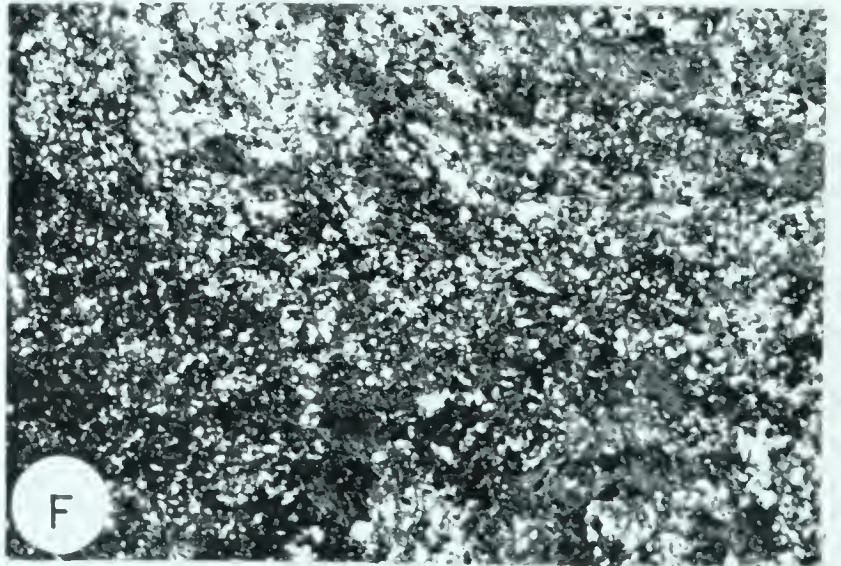
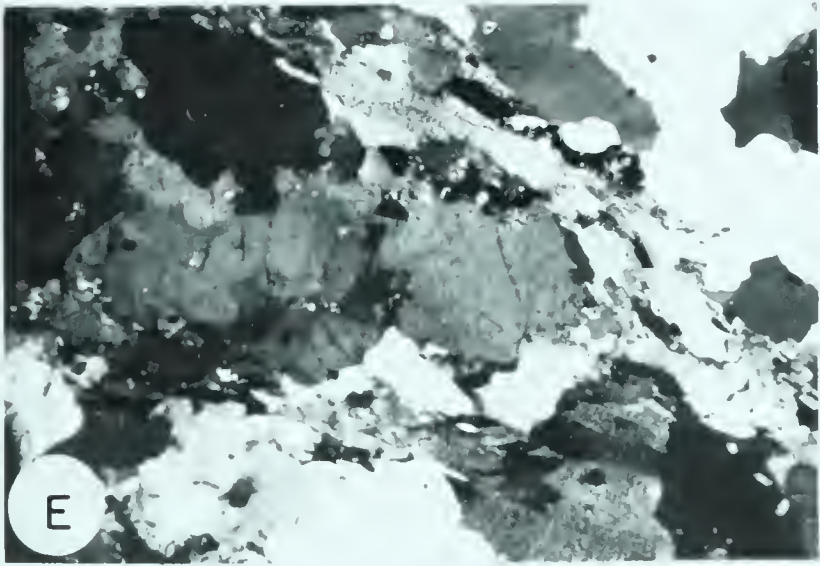
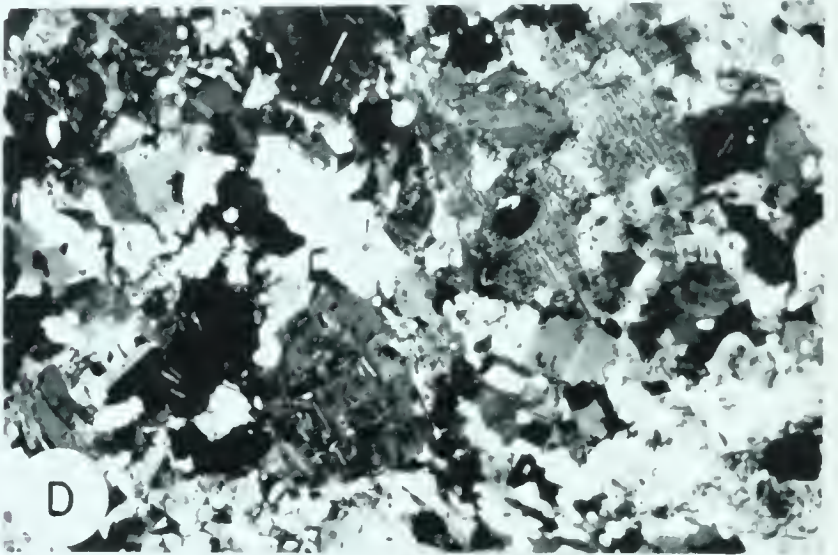
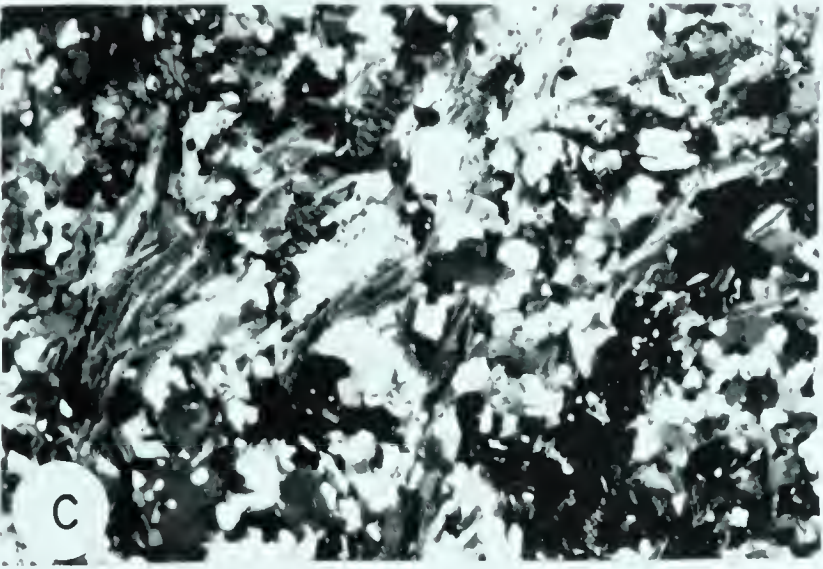
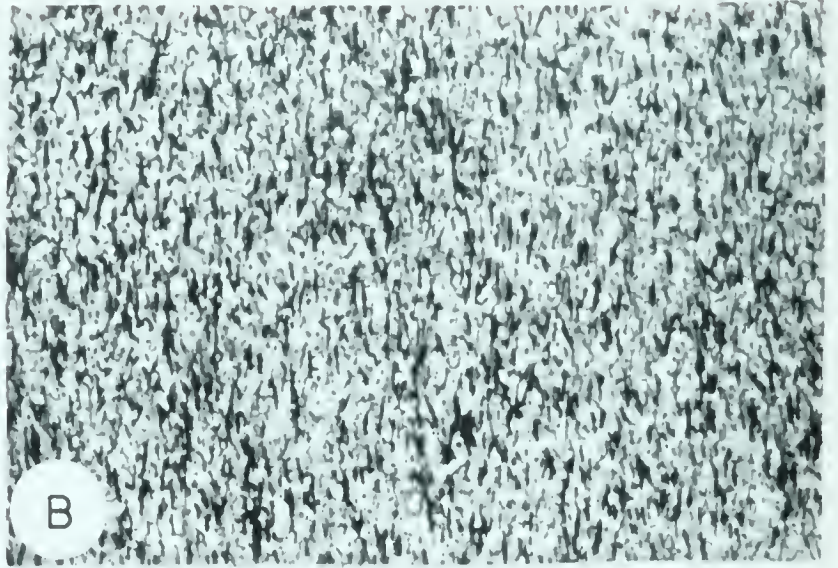
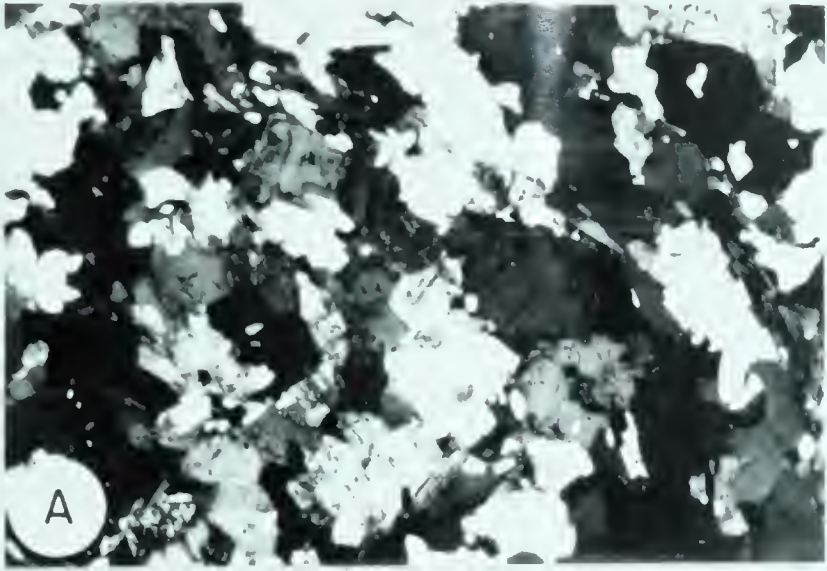


PLATE 6

Basement Metamorphic Rocks

- A. Metaquartzite (4221). Epidote occurs in small stringers in upper half of photograph. Magnification X10. Crossed nicols.
- B. Cordierite-quartz-feldspar gneiss (4483). Partially altered grain of cordierite is shown in left-center of photograph. Surrounding minerals are mainly strained quartz, microcline, and plagioclase. Magnification X10. Crossed nicols.
- C. Same as B above. Photograph shows intensely strained poikiloblastic quartz grain with inclusions of partially altered cordierite. The rim of isotropic alteration around the cordierite grain imparts an apparent high relief. Magnification X10. Crossed nicols.
- D. Altered biotite-quartz rocks (4214). Photograph shows angular grains of quartz (white) suspended in a fine-grained groundmass of sericitic and chloritic composition. Magnification X10. Plane polarized light.
- E. Biotite-quartz-oligoclase gneiss (4216). Strained quartz, altered plagioclase, and biotite are shown in a heterogranular mosaic. Magnification X10. Crossed nicols.
- F. Biotite-quartz-andesine gneiss (4233). Magnification X10. Crossed nicols.
- G. Biotite-quartz-feldspar gneiss (4235). Strained and fractured quartz is shown. Magnification X10. Crossed nicols.

PLATE 6

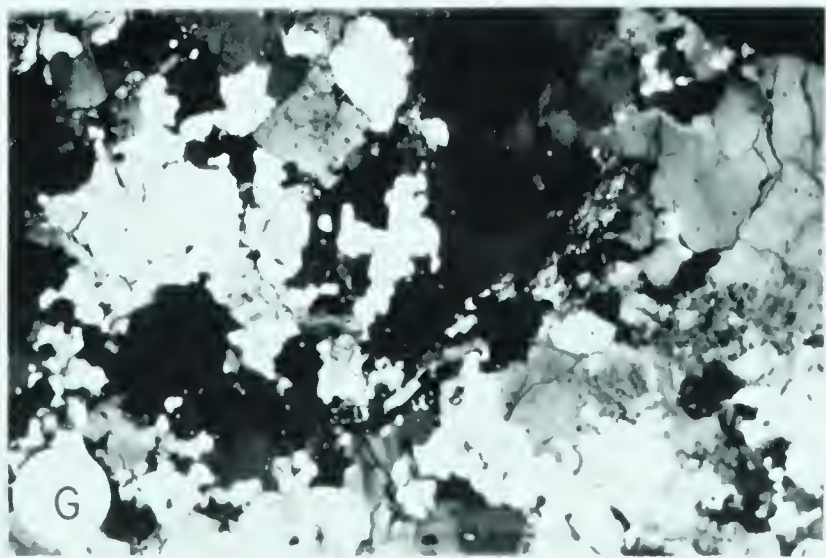
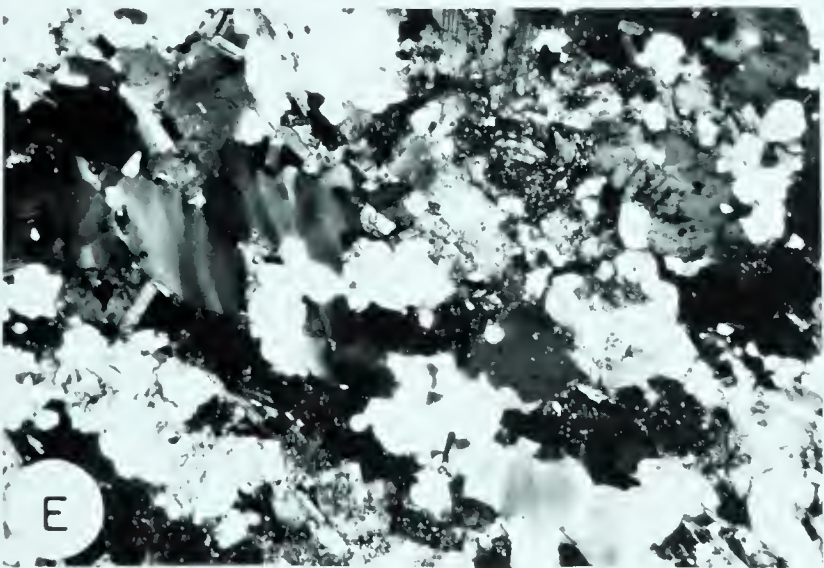
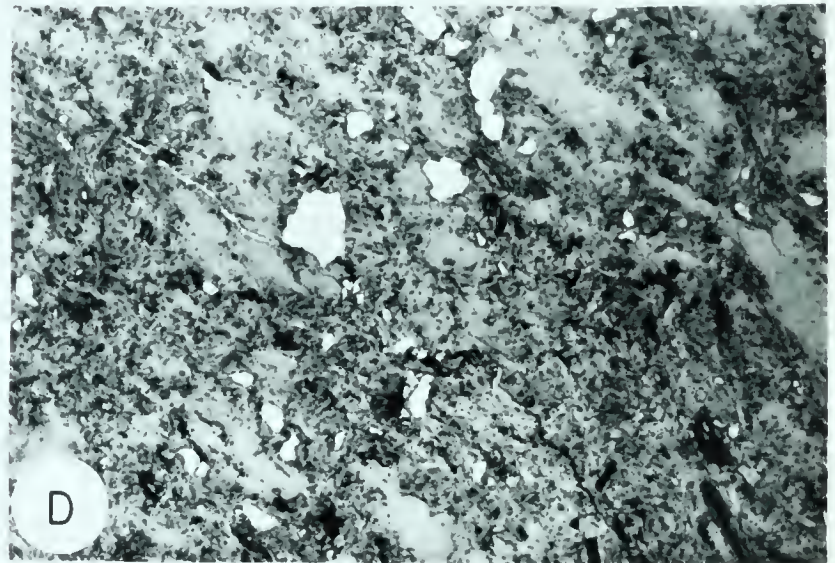
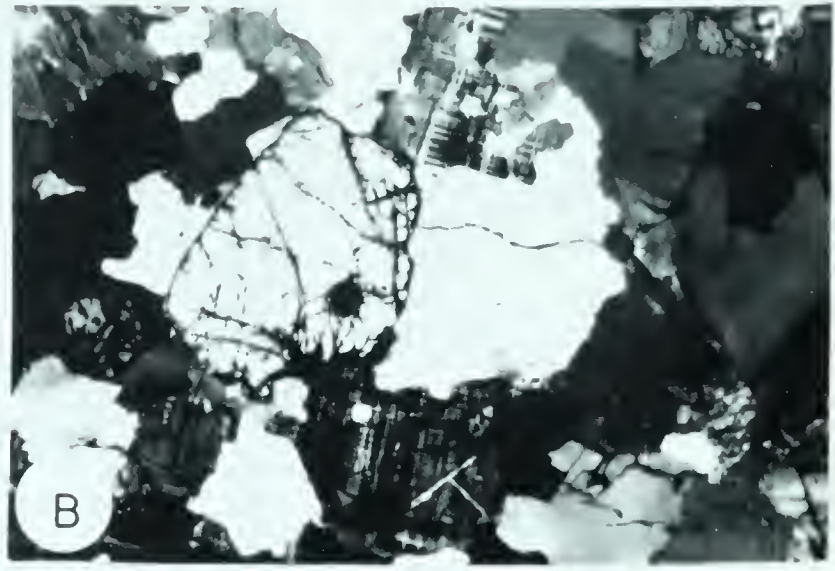


PLATE 7

Basement Metamorphic Rocks and Dated

Rocks from Outcrop Areas

- A. Hypersthene-quartz-feldspar granulite (4678). Photograph shows intensely strained plagioclase crystal with deformed twin lamellae. Magnification X10. Crossed nicols.
- B. Same as A above. Mosaic of anhedral grains of strained quartz and plagioclase is shown. Partially altered pyroxene grain is shown in upper left corner. Magnification X 10. Crossed nicols.
- C. Biotite-quartz-feldspar gneiss (4682). Magnification X10. Crossed nicols.
- D. Epidote-quartz-feldspar gneiss (4681). Epidote and biotite are shown in center of photograph. Magnification X10. Crossed nicols.
- E. Biotite-hornblende hornfels? (RB-61-396-2). Quartz and feldspar (white); and hornblende and biotite (dark grey) form a heterogranular mosaic. Magnification X10. Crossed nicols.
- F. Pyroxene-labradorite-hornblende granulite (4524). Hornblende and pyroxene (medium to dark grey) form the bulk of the rock. Magnification X10. Plane polarized light.
- G. Porphyritic biotite granite (4686). Phenocrysts are not shown in photograph. Granitic groundmass is composed of quartz, feldspar, and biotite. Magnification X10. Crossed nicols.

PLATE 7

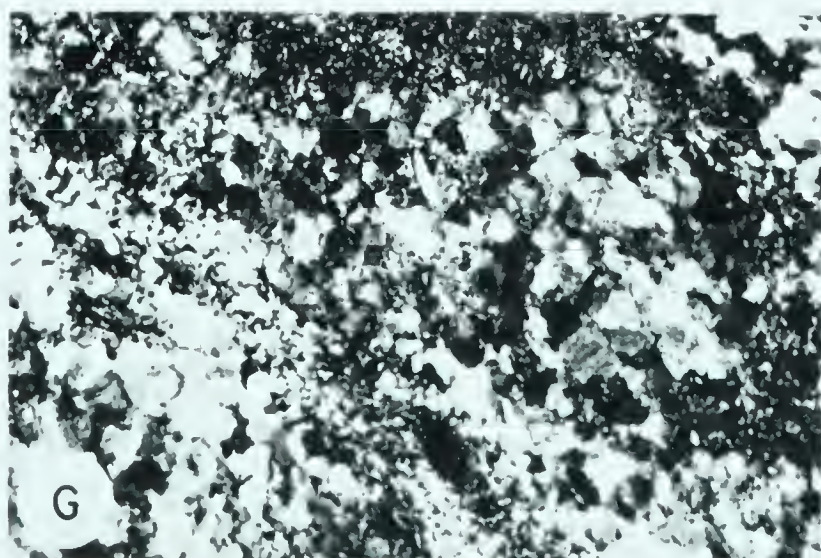
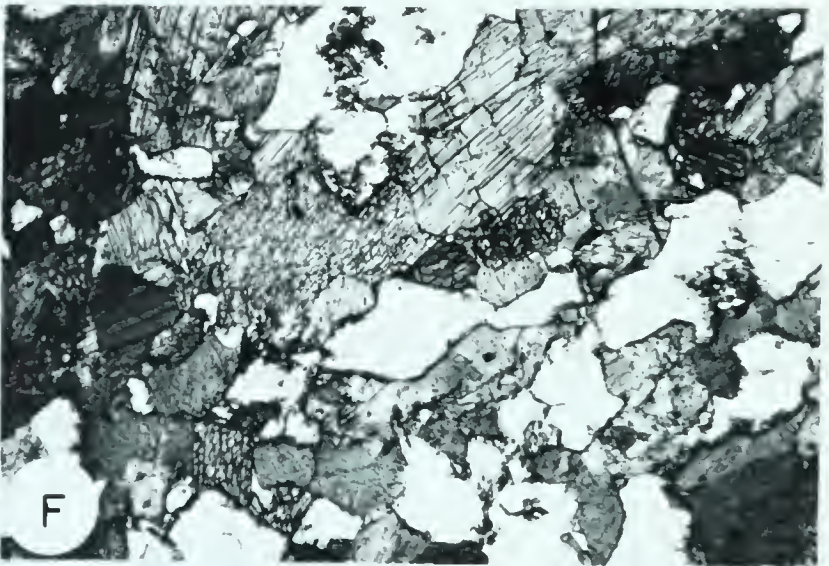
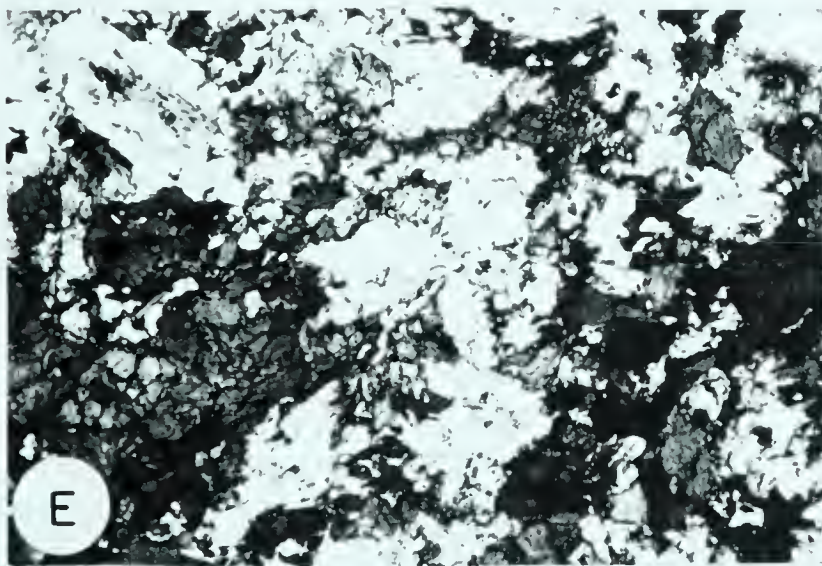
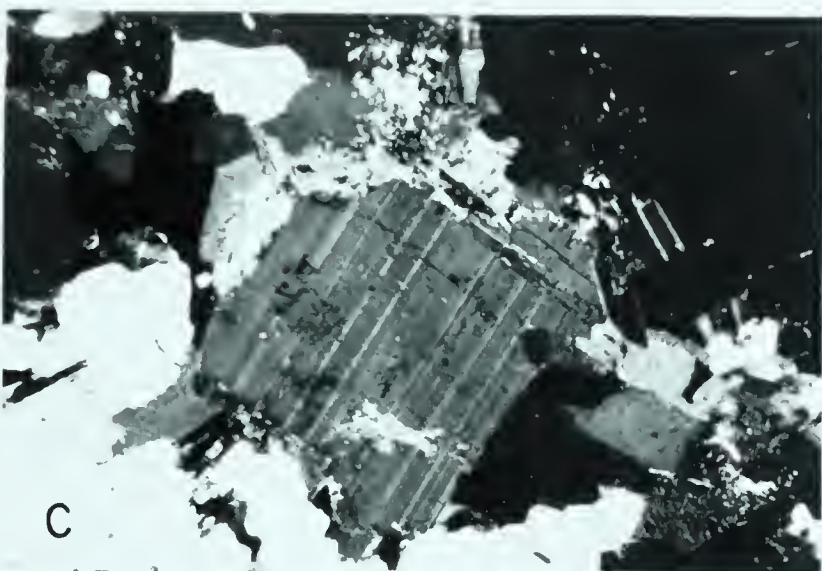
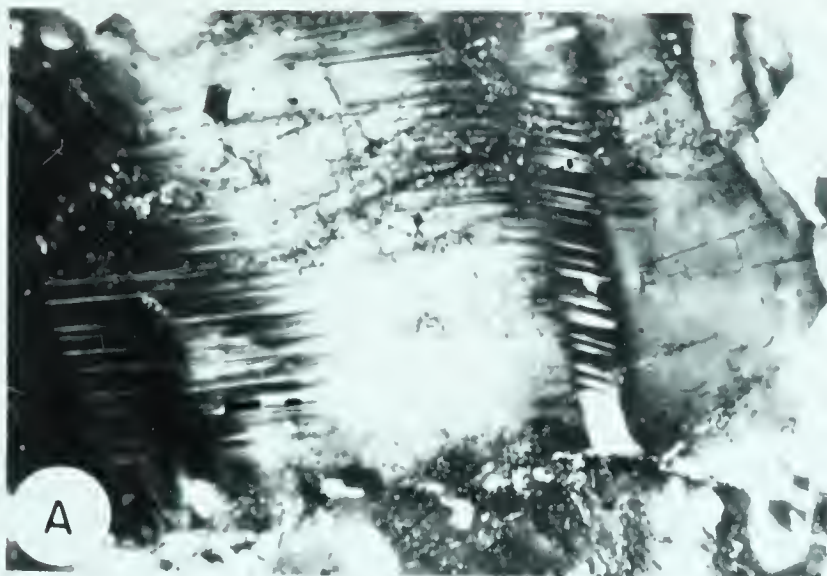


PLATE 8

Dated Outcrop Rocks

- A. Hornblende quartz diorite (4683 Au 23-2). Fine-grained mosaic of quartz, feldspar, and mafic minerals is shown. Magnification X10. Crossed nicols.
- B. Altered quartz diorite cobble (4683 Au 23-3). Effects of shearing and alteration are evident. Magnification X10. Crossed nicols.
- C. Biotite-plagioclase amphibolite (4683-Au 23-5). Dark areas are mainly biotite and hornblende; light areas are quartz and feldspar. Magnification X10. Plane polarized light.
- D. Hornblende quartz diorite (4683 Au 22-3). Photograph shows dioritic texture formed by plagioclase and hornblende grains. Magnification X10. Crossed nicols.
- E. Hornblende diorite (4500 Au 8-1). Mosaic of plagioclase (white) and hornblende (dark grey) is shown. Magnification X10. Plane polarized light.
- F. Muscovite quartz monzonite (4500 Jn 10-19). Photograph shows typical granitic texture formed by quartz and feldspars. Magnification X10. Crossed nicols.
- G. Biotite-quartz-feldspar gneiss (4500 Ma 31-1). Composite elongate lenses of quartz are shown. Finer grained minerals are mainly quartz, feldspar, and biotite. Magnification X10. Crossed nicols.
- H. Pyroxene-andesine-hornblende gneiss (4500 Ma 30-1). Pyroxene grains (light grey) are shown surrounded by hornblende (dark grey). Quartz and feldspar appear white. Magnification X10. Plane polarized light.

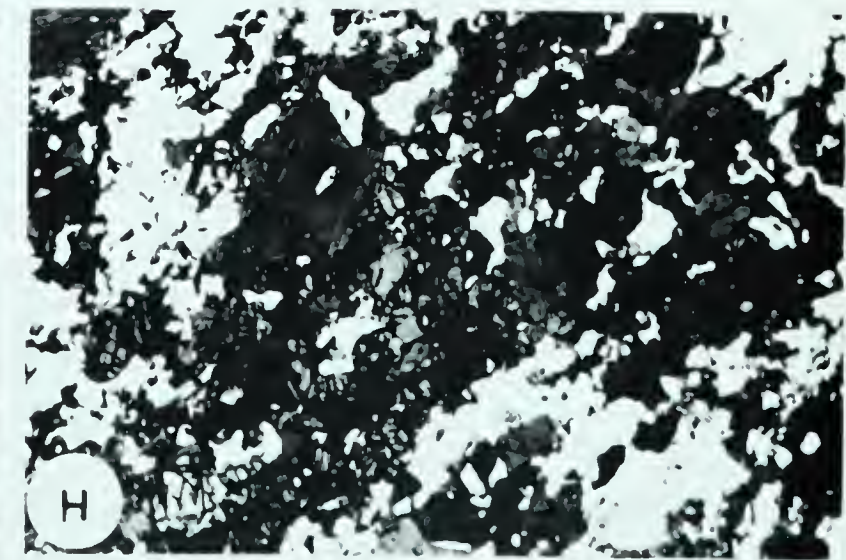
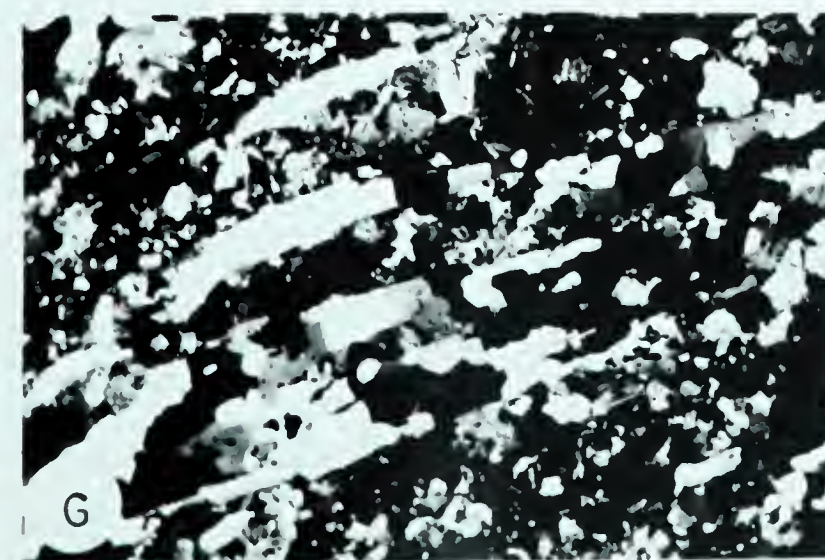
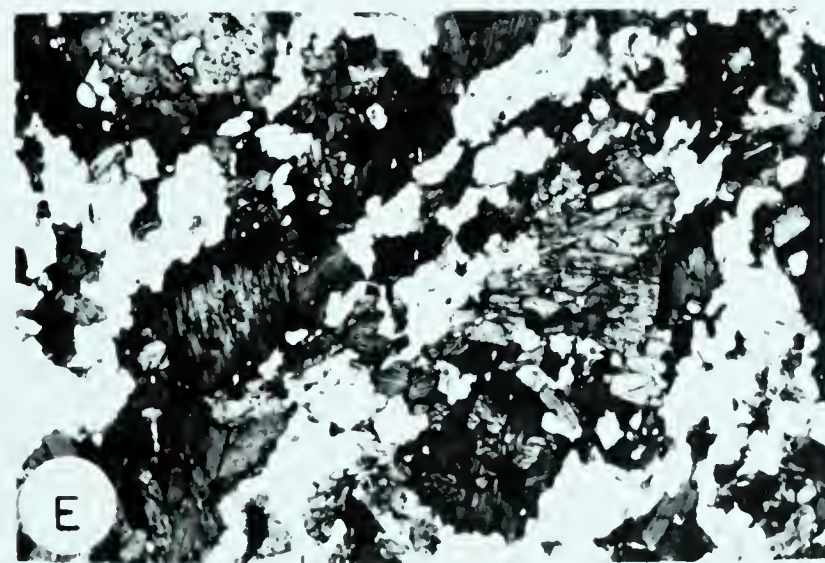
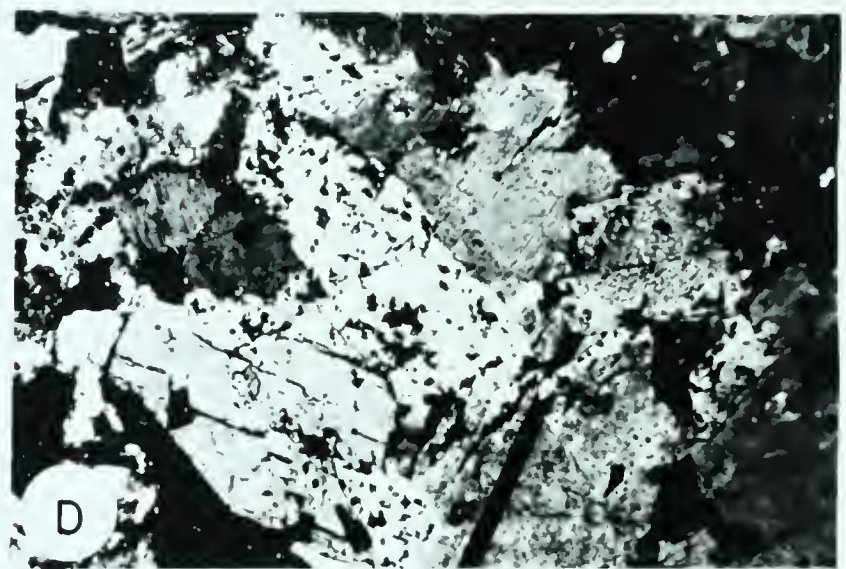
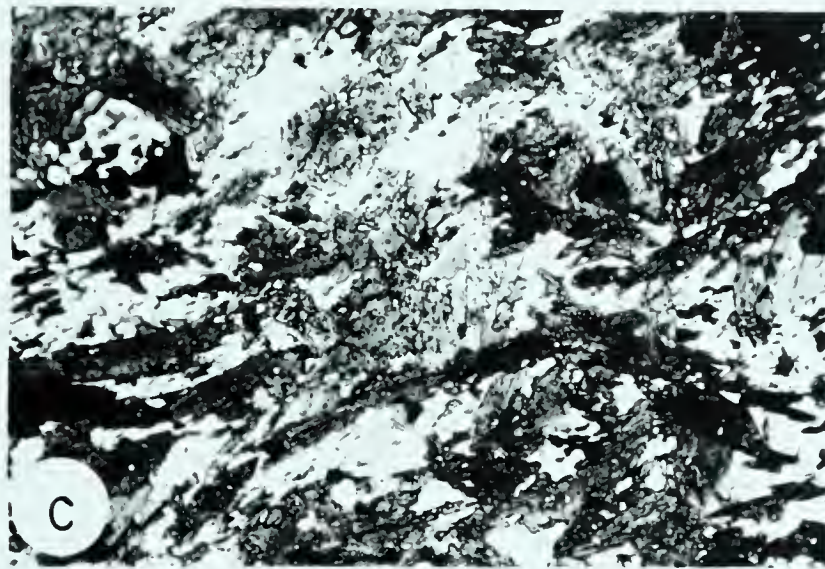
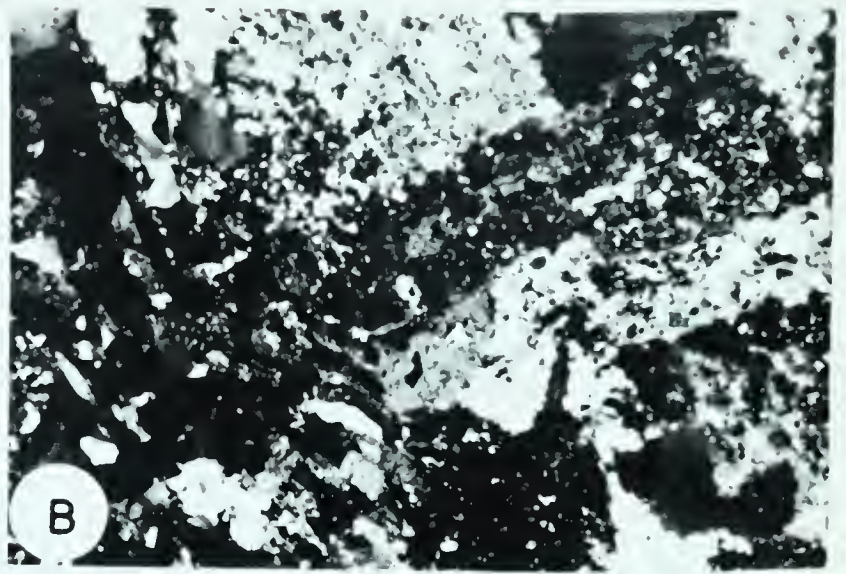
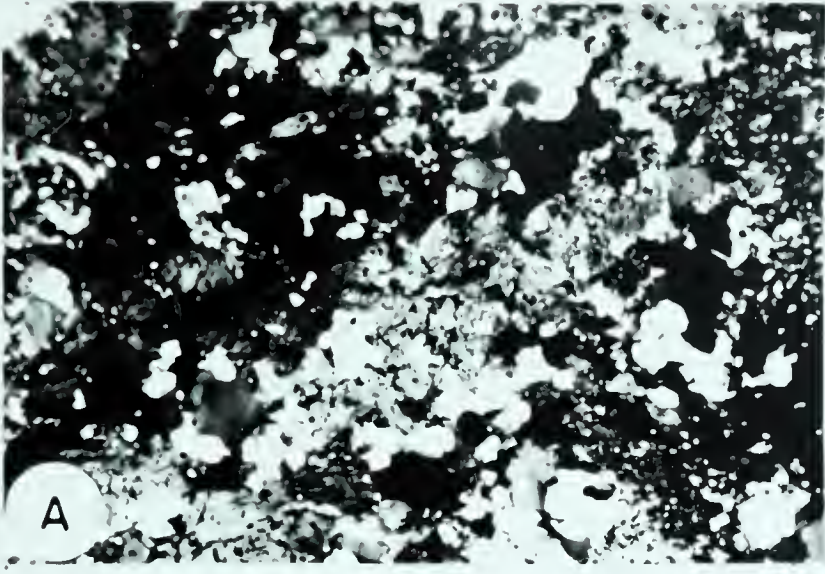
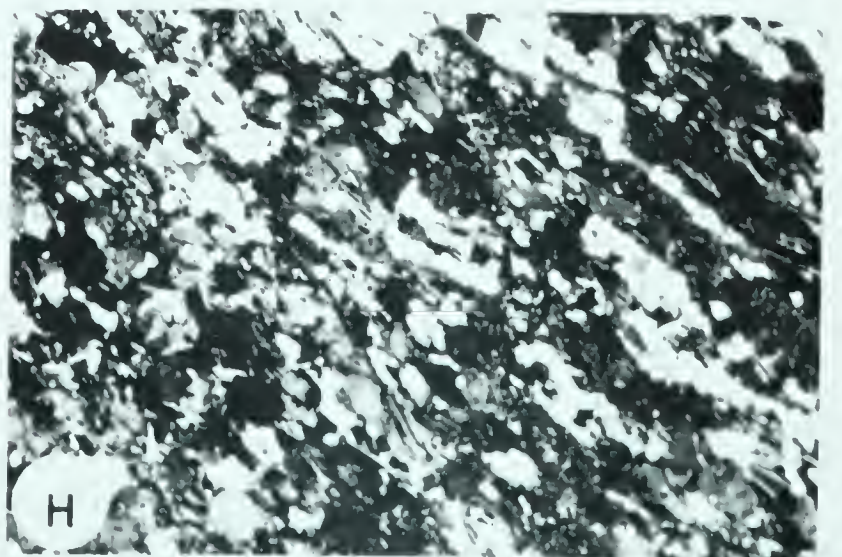
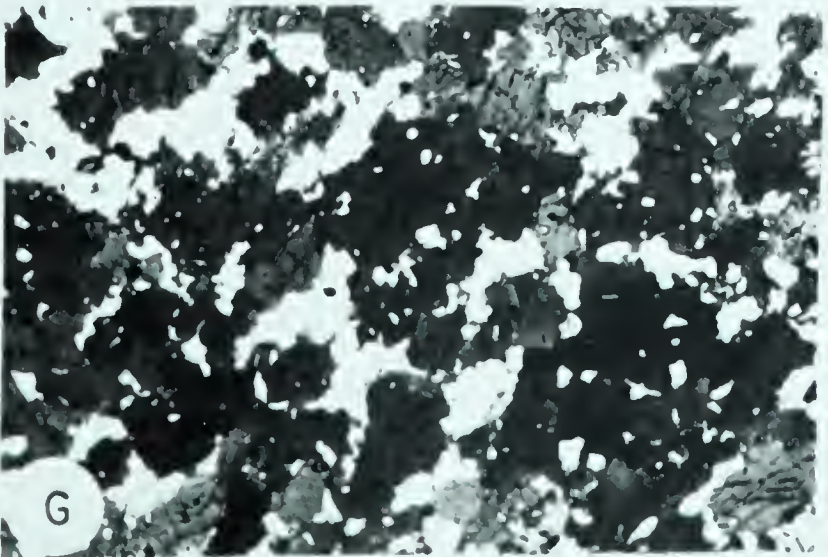
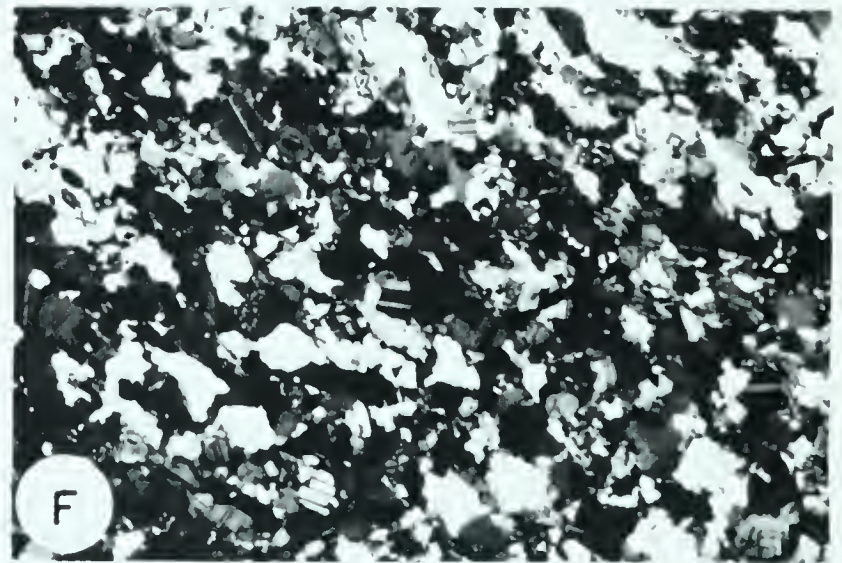
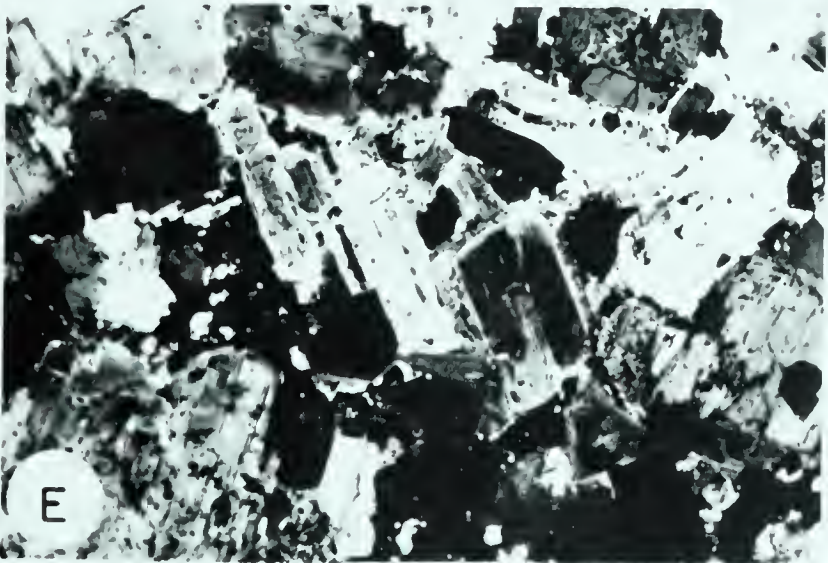
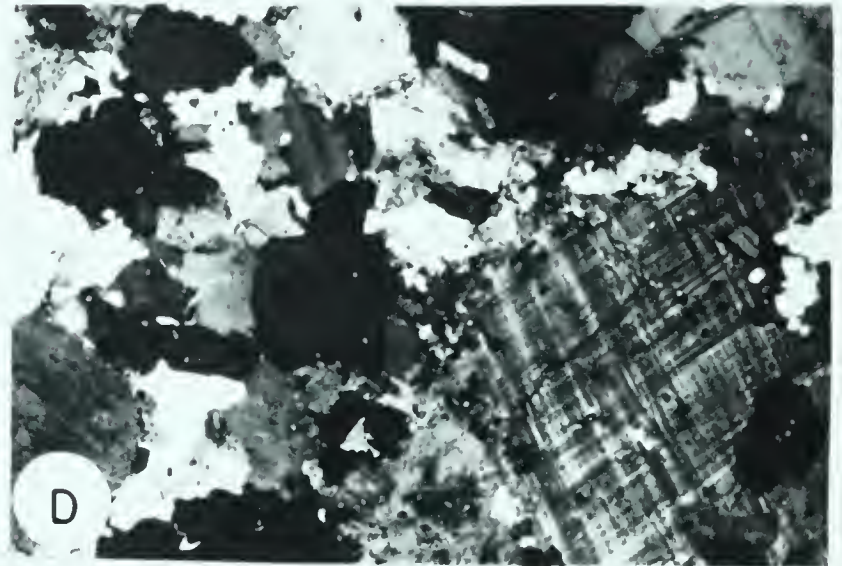
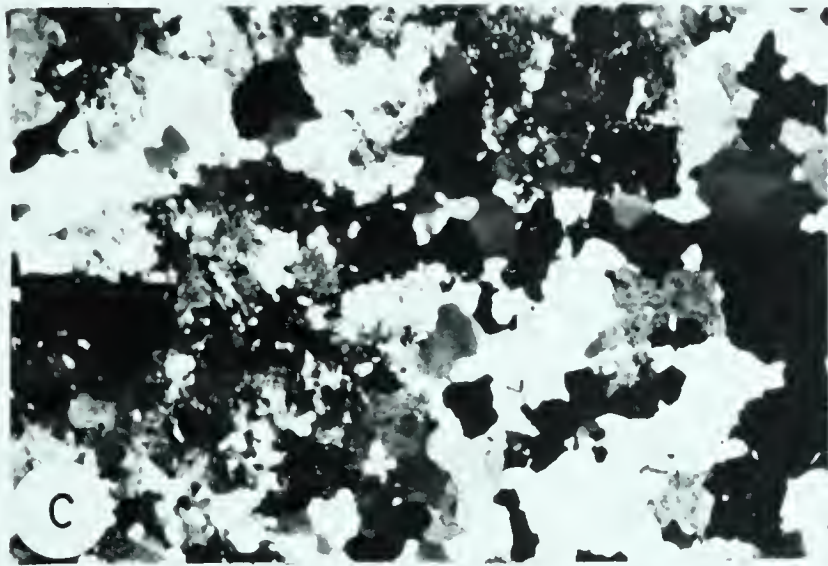
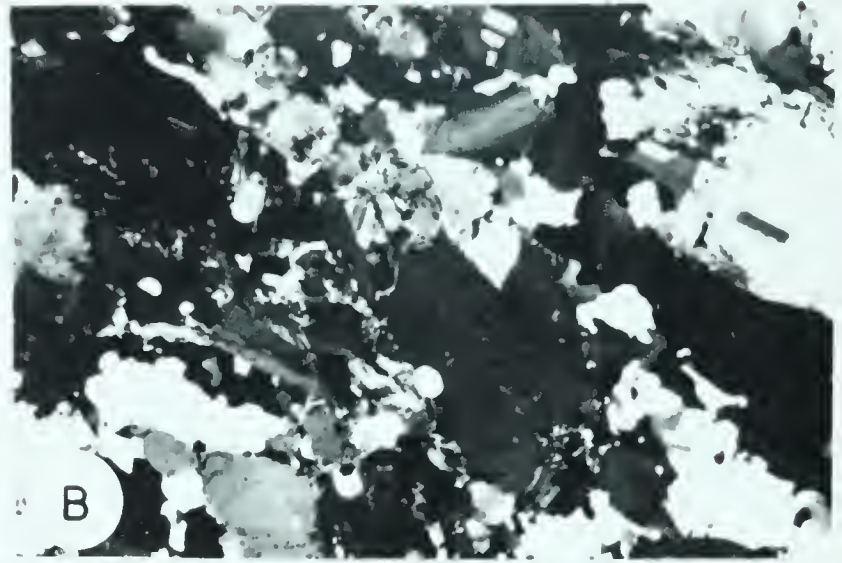
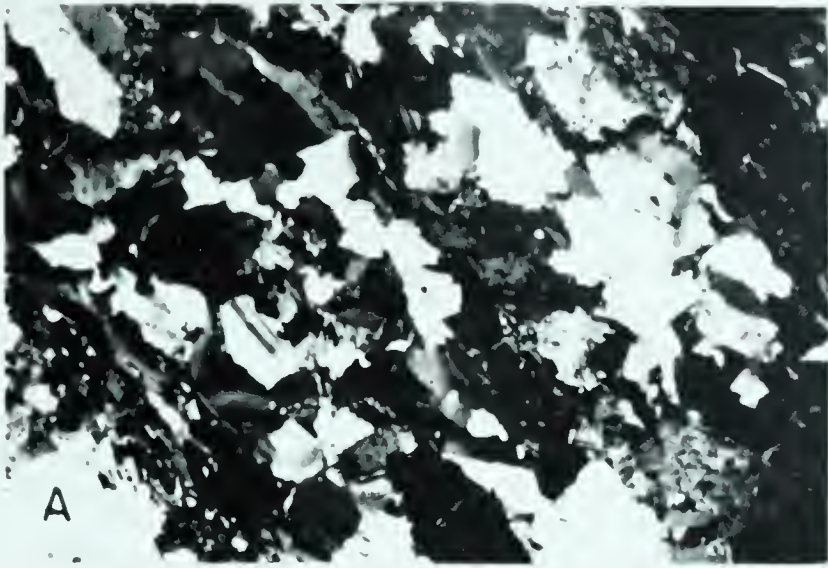


PLATE 9

Dated Outcrop Rocks

- A. Biotite-quartz-feldspar gneiss (4499A). Magnification X10. Crossed nicols.
- B. Biotite granodiorite (4499B). Mosaic mainly of quartz and oligoclase. Magnification X10. Crossed nicols.
- C. Quartz diorite cobble (4499C). Photograph shows mosaic of quartz and sericitized plagioclase. Magnification X10. Crossed nicols.
- D. Biotite-quartz-feldspar gneiss (4498A). Large grain of well twinned microcline is shown in left half of photograph. Magnification X10. Crossed nicols.
- E. Hornblende-biotite granodiorite (4498B). Photograph shows well developed granodioritic texture formed by subhedral to euhedral zoned andesine and anhedral quartz. Magnification X10. Crossed nicols.
- F. Biotite-hornblende-quartz-andesine gneiss (4685-10). Magnification X10. Crossed nicols.
- G. Plagioclase amphibolite (4684-7). Photograph shows poikiloblastic nature of hornblende (dark grey). Magnification X10. Crossed nicols.
- H. Porphyroblastic biotite schist (4684-6). Photograph shows well developed lepidoblastic texture. Porphyroblasts of microcline were not evident in thin section. Magnification X10. Crossed nicols.

PLATE 9



APPENDIX B

Petrographic Descriptions of Basement and Dated Outcrop Samples

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No.: 2182

Well Name: Tidewater Crown Johnstone Lake

Location: 9-20-12-2 W 3

Sample Depth: 7785 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. brownish grey

Grain size: aphanitic and fine

Texture: porphyritic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary)

Porphyritic. Phenocrysts, anhedral to subhedral set in a microphaneritic groundmass.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated)

PRIMARY		METAMORPHIC	ALTERATION	
Essential:				
Microcline	14		Sericite	2.6
Quartz	7.5		Epidote	0.7
Plagioclase An 9	7.2		Chlorite	tr
Biotite	2.4		Carbonate	tr
			Leucoxene	tr
Groundmass	65			
Accessory:				
Hornblende	tr			
Apatite	tr			
Mag.-Il.	tr			
Sphene?	tr			

SPECIAL FEATURES AND INTERPRETATIONS:

*mode after Burwash, 1957

1. The groundmass is composed mainly of a fine-grained equigranular mosaic of anhedral quartz and feldspar, mostly K-feldspar.

2. Many of the quartz phenocrysts are anhedral composite grains. Some, however, show bipyramidal outlines. Both quartz and plagioclase show poikilitic overgrowths in places with numer inclusions of matrix grains.

3. Microcline has both patch and vein perthite.

4. Opaque minerals are dispersed throughout the slide and in places they are altered to leucoxene.

CLASSIFICATION: Rhyolite porphyry
Johannsen No. 216

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 2211
Well Name. Shell Swan River No. 1

Location. 9-1-37-28 W 1
Sample Depth. 2044-
2045 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. dark greenish grey
Grain size: fine, 0.2 to 0.5 mm
Texture: microphaneritic

MICROSCOPIC DESCRIPTION:

Texture and stucture (primary and secondary):

Anhedral inequigranular. The main mass is approximately equigranular with an average grain size of about 0.2 mm. Some of the quartz grains distinctly larger (about 0.5 mm). Hiatus in grain size is not evident in hand specimen and the term porphyritic is not used.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:		Chlorite 1.1
Quartz 33		Kaolinite (?) tr
Perthite 64		Iron oxides tr
Plagioclase An 19		
Microcline		
		INTRODUCED
Accessory:		
Biotite 2.0		
Apatite tr		
Zircon tr		
Mag.-Il. tr		

SPECIAL FEATURES AND INTERPRETATION:

Sp gr = 2.61

1. Feldspars occur in three distinct phases: (1) the main mass is strongly perthitic in which one phase has been more or less completely altered to kaolinite or similar clay mineral, (2) discrete grains of plagioclase, and (3) discrete grains of microcline. Phases (2) and (3) are counted with (1).
2. Locally biotite has altered to chlorite.
3. Small veinlets of chlorite cut the essential minerals in places.

Classification: Microgranite or microgranodiorite
Johannsen No.: 126-127

Petrographer:
Z. E. Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 2428

Location. 7-14-56-17 W 3

Well Name. Canadian Seaboard Divide No. 2

Sample Depth. 4332 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. dark greenish grey

Grain size: medium, 1 to 4 mm

Texture: Granitic

MICROSCOPIC DESCRIPTION:

Texture and structure (both primary and secondary):

Anhedral granular.

Mortar structure developed around some of the larger grains.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:		
Perthitic orthoclase 40		Chlorite tr
Plagioclase An 24 28		Sericite tr
Quartz 26		
Hypersthene 4.1		
Accessory:		
Hornblende 0.4		
Biotite tr		
Mag.-Il. tr		
Epidote tr		
Zircon tr		
Pyrite tr		

Special Features and Interpretation:

Sp gr= 2.65

1. Hypersthene shows moderate pleochroism from blue to red and contains small, poorly oriented intergrowths of clinopyroxene. Hornblende and biotite are associated with the hypersthene and may represent alteration products.

2. The perthitic development in orthoclase is very fine (microperthite).

3. Myrmekite occurs in minor amounts at some plagioclase-orthoclase contacts.

4. Post-crystallization deformation is indicated by: (a) mortar structure, (b) strained quartz, plagioclase, and orthoclase, and (c) iron stained fractures common throughout the rock.

CLASSIFICATION: Hypersthene quartz monzonite (charnockite)
Johannsen No. 226"

Petrographer:
Z. E. Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 2429

Location. 13-21-61-15 W 3

Well Name. Canadian Seaboard Meadow Lake No. 1 Sample Depth. 2767 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. pinkish buff

Grain size: medium, 0.5 to 1.5 mm

Texture: granitic

MICROSCOPIC DESCRIPTION:

Texture and structure (both primary and secondary)

Anhedral inequigranular.

Some suggestion of mortar structure.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:		Leucoxene tr
Orthoclase 41		Iron oxides tr
Quartz 35		"Dusty" alteration of
Plagioclase An 17 22		orthoclase and
Biotite 2.0		plagioclase
		INTRODUCED
Accessory:		
Mag.-Il. 2.0		
Zircon tr		
Sphene tr		

SPECIAL FEATURES AND INTERPRETATION:

Sp gr = 2.61

1. Quartz, orthoclase, and plagioclase show moderate straining.
2. Myrmekite occurs in minor amounts.
3. Vein perthite and patch antiperthite are present.

CLASSIFICATION: Biotite granite
Johannsen No. 126"

PETROGRAPHER:
Z. E. Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 2430

Location. 9-21-63-8 W 3

Well Name. Canadian Seaboard Meadow Lake No. 2 Sample Depth. 2061 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. dark grey

Grain Size: medium, 1 to 5 mm

Texture: granitic

MICROSCOPIC DESCRIPTION:

Texture and structure (both primary and secondary):

Subhedral inequigranular.

In places hornblende and biotite are poikilitic.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:		Minor indeterminate alteration on plagioclase. May be epidote and carbonate.
Plagioclase An 28 34		
Microcline 27		
Quartz 13		
Biotite 13		
Hornblende 10		
		INTRODUCED
Accessory:		
Sphene 1.1		
Mag.-Il. 1.0		
Apatite tr		
Zircon tr		

SPECIAL FEATURES AND INTERPRETATION:

Sp gr = 2.73

1. Perthite and antiperthite are present in feldspar phases.
2. Myrmekite present locally.
3. In places poikilitic hornblende and biotite contain abundant, well rounded inclusions of quartz.
4. Zircon is abundant as an accessory and in places grains up to 0.2 mm were noted.

CLASSIFICATION: Hornblende-biotite quartz monzonite
Johannesn No. 227"

PETROGRAPHER:
Z. E. Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 3633
Well Name. Mobil Woodley Sinclair
Cantuar X-2-21

Location. 2-21-16-17 W 3
Sample Depth. 7285- 7305 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. medium grey
Grain size: fine and coarse, 0.6 and 10-15 mm
Texture: granitic porphyritic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary):

Porphyritic with subhedral granular groundmass. Phenocrysts of feldspar up to 15 mm in length and rounded quartz up to 10 mm in diameter. Average grain size of granitic groundmass is about 0.6 mm. Some sutured grain boundaries present.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance, and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:*		
Quartz 41		Chlorite tr
Microcline 31		Sericite tr
Plagioclase An 7 20		Carbonate tr
Biotite 7.7		
		INTRODUCED
Accessory:		
Epidote 0.8		
Allanite 0.6		
Hornblende 0.3		
Mag.-Il. 0.3		
Zircon tr		
Apatite tr		
Fluorite tr		

SPECIAL FEATURES AND INTERPRETATION:

Sp gr = 2.66 *Phenocrysts comprise about 35 percent of total rock.

1. In hand specimen the rock is characterized by blue quartz phenocrysts which in thin section show intense straining with some fracturing.
2. Microcline has both vein and patch type perthitic intergrowths and in places it is poikilitic.
3. Plagioclase is moderately altered to sericite but microcline is very fresh.
4. Mafic minerals occur together. In places allanite has well developed euhedral overgrowths of epidote

CLASSIFICATION: Porphyritic biotite granite
Johannsen No. 216"

PETROGRAPHER:
Z. E. Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 3634

Well Name. B. A. Wilhelm 1-9

Location. 1-9-17-14 W 3

Sample Depth. 6735- 6755 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. greyish black

Grain size: very fine grained, coarse grained, 0.05 and 2 mm

Texture: aphanitic porphyritic

MICROSCOPIC DESCRIPTION:

Texture and structure (both primary and secondary):

Subhedral to euhedral phenocrysts are suspended in a very fine grained anhedral granular groundmass. Clusters of hornblende and biotite occur. Average grain size of the phenocrysts is about 2 mm.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance, and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:		
Phenocrysts 23		Epidote tr
(Plagioclase 8)		Carbonate tr
(Microcline 10		White mica tr
(Hornblende and biotite 5)		Lucasene tr
Groundmass 77		
(Quartz 33)		
(K-feldspar 33)		
(Hornblende and biotite 11)		
		INTRODUCED
Accessory:		
Mag.-Il. tr		
Apatite tr		
Sphene tr		

SPECIAL FEATURES AND INTERPRETATION:

Sp gr = 2.69

1. Microcline phenocrysts shown strong development of perthitic intergrowths.
2. Plagioclase, including the perthitic intergrowths in the microcline, is intensely altered. Composition determination is impossible.
3. The composition of the groundmass was estimated visually because of fine grain size. Most of the feldspar in the groundmass is thought to be K-feldspar on the basis of comparative relief with quartz.
4. Hornblende and biotite occur in clusters with an approximate ratio of hornblende to biotite of 10 to 1.

CLASSIFICATION: Rhyolite or quartz dacite porphyry
(depending on An content of plagioclase)

PETROGRAPHER:
Z. E. Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4213

Location. 15-5-46-9 W 2

Well Name. California Standard Bannock 15-5

Sample Depth. 2532 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. greenish grey

Grain Size: fine to medium, 0.3 to 4 mm

Texture: granitic

MICROSCOPIC DESCRIPTION:

Texture and structure (both primary and secondary)

- (1) Primary: medium grained, subhedral inequigranular
 (2) Secondary: fractures; strained and broken minerals.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:		Altered plagioclase) 30
Quartz 27		Kaolinite ?
Perthitic orthoclase 20		Carbonate 6
Biotite 13		Chlorite tr
		Leucoxene tr
		INTRODUCED
Accessory:		Some carbonate in small fractures.
Pyrite 5		Gypsum ?
Apatite tr		
Zircon tr		
Sphene tr		
Mag.-Il. tr		

SPECIAL FEATURES AND INTERPRETATIONS:

Sp gr = 2.58

1. Plagioclase grains have been altered to a fine-grained mass of kaolinite or similar clay mineral.
2. Veinlets of colorless, low birefringent, low relief mineral occur in orthoclase. Mineral is probably gypsum.
3. Microperthitic orthoclase contains numerous small opaque inclusions.
4. Chlorite is concentrated in small microshear zones.

Altered condition of rock is due to fracturing and subsequent chemical alteration possibly as a result of weathering.

CLASSIFICATION: Altered biotite granite

PETROGRAPHER
 Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4214

Location. 15-18-10-27 W 1

Well Name. California Standard Daly 15-18

Sample Depth. 5360 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. greenish grey

Grain size: aphanitic and fine grained

Texture: massive aphanitic

MICROSCOPIC DESCRIPTION: (primary and secondary)

Main mass of rock is very fine grained. Larger grains (about 0.2 mm) of quartz, biotite, and accessory minerals are suspended in the fine-grained groundmass. Rock appears to have undergone considerable chemical, and possibly mechanical, alteration. In places, micaceous minerals of groundmass show lepidoblastic texture.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:		
Groundmass 93		Chlorite 1 Leucoxene tr
Quartz 3		
Biotite 1		
Accessory:		INTRODUCED
Mag.-Il. 1		
Sphene tr		
Apatite tr		

SPECIAL FEATURES AND INTERPRETATION:

Sp Gr = 2.28

- The groundmass seems to be comprixed essentially of two minerals:
 - sericite which shows crude alignment in places.
 - very fine-grained, low-birefringent mineral which may be chlorite but absolute identification is impossible optically.
 The groundmass is stained yellowish brown by iron oxides.
- Larger grains of biotite have in places altered to chlorite but in other places it is completely fresh.
- Quartz occurs as subangular to angular grains which form clusters. This may be the result of physical breakdown of larger grains but straining is not evident and grains are not in optical continuity although rotation could have occurred.
- Subhedral to euhedral apatite is abundant as an accessory.
- Granular sphene and leucoxene are restricted to the groundmass.

CLASSIFICATION: Altered biotite-quartz rock
Possibly a fine-grained igneous rock which has
undergone intense chemical alteration.

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4215

Location. 1-15-48-17 W 2

Well Name. California Standard Ratner 1-15

Sample Depth. 2594 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. greyish black

Grain size: fine (average is 0.1 mm)

Texture: Schistose

MICROSCOPIC DESCRIPTION:

Texture and Structure (primary and secondary):

Anhedral to subhedral, equigranular, lepidoblastic. Both micas show very well developed alignment.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Quartz 33 Microcline 25 Biotite 22 Muscovite 17 Mag.-Il.-Py. 3	Carbonate tr Chlorite tr
Accessory:	Tourmaline tr Apatite tr Zircon tr Garnet tr	INTRODUCED

SPECIAL FEATURES AND INTERPRETATION:

Sp Gr = 2.70

1. Microcline is slightly altered and poorly twinned.
2. Quartz shows slight undulatory extinction and in places contains minute inclusions in abundance.
3. Biotite and muscovite are commonly associated and locally interlayered. Biotite contains opaque inclusions and a few zircons.
4. Apatite, tourmaline, zircon, and garnet occur in trace amounts. The first three are likely detrital but garnet occurs as incipient porphyroblasts.
5. Opaque minerals are dispersed throughout the rock and typically occur as small, rounded grains.
6. Absence of plagioclase was confirmed by X-ray pattern obtained of light fraction.

CLASSIFICATION: Muscovite-biotite schist

Almandine-amphibolite or upper greenschist facies

PETROGRAPHER

Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4216

Well Name. California Standard Wawanesa

Location: 3-1-8-18 W 1

Sample Depth: 3825 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. dark grey

Grain size: medium (average is about 1 mm)

Texture: gneissic, poorly banded

MICROSCOPIC DESCRIPTION

Texture and Structure (primary and secondary):

Anhedral inequigranular. Some sutured grains. In places essential minerals form a simple mosaic.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Plagioclase An 28 52 Quartz 31 Biotite 15	Chlorite 0.3 Epidote tr Sericite tr
	Epidote 2.0 Hornblende 0.7 Apatite 0.1 Zircon tr	INTRODUCED

SPECIAL FEATURES AND INTERPRETATION:

Sp Gr = 2.73

1. Alteration of plagioclase varies from nil to intense where much sericite and epidote has been produced.
2. Biotite is locally altered to chlorite and contains microlites of an oriented opaque mineral.
3. Quartz has sutured boundaries in places and is typically intensely strained.
4. There is no evidence in thin section which substantiates a metamorphic origin for this rock. Interpretation is based on gneissic structure evident in hand specimen.

CLASSIFICATION: Biotite-quartz-oligoclase gneiss
Almandine-amphibolite facies

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4217

Location: 8-30-64 W 3

Well Name. Canadian Seaboard Meadow Lake No. 3 Sample Depth. 2435 ft

MEGASCOPIIC DESCRIPTION:

Color: f.s. light brownish grey

Grain size: medium (average is about 2 mm)

Texture: porphyroblastic gneissic, crudely banded

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary)

Subhedral inequigranular, foliated. Large augen or porphyroblasts seen in hand specimen are composed of mosaic intergrowth of quartz and feldspar.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated).

PRIMARY	METAMORPHIC	ALTERATION
Essential;	Plagioclase An 22 33 Microcline 28 Quartz 27 Biotite 9.3	Chlorite 1.0 Carbonate 0.5 Leucoxene tr Sericite tr
Accessory:	Apatite 0.2 Mag.-Il. 0.2 Zircon 0.1 Muscovite tr Sphene tr	INTRODUCED

SPECIAL FEATURES AND INTERPRETATION:

Sp gr = 2.67

1. Microcline is perthitic with the vein-type intergrowths.
2. Plagioclase is slightly zoned or strained and in places altered cores of plagioclase are rimmed with clear, unaltered, untwinned plagioclase.
3. Zircon is zoned, rounded, and partially metamict. Appears to be detrital.
4. Small crystals of sphene are partially altered to leucoxene and associated with carbonate and chlorite. (alteration from hornblende?)
5. Minor myrmekite is present.

CLASSIFICATION: Biotite-quartz-feldspar gneiss
 Almandine-amphibolite facies.

PETROGRAPHER
 Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4218

Well name. Ceepee Annette 10-25

Location. 10-25-36-5 W 2

Sample depth. 3368 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. dark greenish grey

Grain size: fine (average about 0.5 mm)

Texture: Schistose with small ellipsoids. (foliation parallel to axis of core, ie. 90° dip)

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary):

Anhedral, more or less even grained, foliated. Ellipsoids range from 0.5 mm to 1 cm in circular section and up to 10 cm in width. These ellipsoidal areas are crudely outlined by micaceous minerals and carbonate.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated).

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Quartz Feldspar] 50 Sericite 30 Carbonate 10 Biotite 10	Leucoxene tr Chlorite tr
Accessory:	Granular sphene tr	INTRODUCED

SPECIAL FEATURES AND INTERPRETATIONS:

Sp gr = 2.53

Mode visually estimated.

1. Due to the fine grained character of the rock the mode given above is at best only a crude approximation.

2. Only a few of the plagioclase grains are twinned. Much of the material which appears to be quartz by actually be plagioclase. No K-feldspar was noted but some may be present.

3. Small ellipsoids have carbonate in center which is slightly coarser grained than that in groundmass.

CLASSIFICATION: Calcareous quartz-mica schist
Greenschist facies (?)

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4219

Well Name. Ceepee Baildon 2-11

Location. 2-11-56-26 W 2

Sample Depth. 7738 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. light brownish grey

Grain size: coarse, 10 mm.

Texture: granitic

MICROSCOPIC DESCRIPTION:

Texture and structure (both primary and secondary):

Subhedral inequigranular. Average grain size is about 10 mm but microcline crystals attain lengths of 5 cm in places.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:		Chlorite tr
Microcline 37		Epidote tr
Quartz 34		Leucoxene tr
Plagioclase An 34 25		Carbonate tr
Biotite 2.1		Sericite tr
Accessory:		INTRODUCED
Mag.-Il. tr		
Apatite tr		
Zircon tr		
Sphene tr		
Garnet tr (seen in hand specimen only)		

SPECIAL FEATURES AND INTERPRETATIONS:

Sp gr = 2.66

1. Microcline is perthitic and plagioclase is antiperthitic of the patch variety.
2. Myrmekitic intergrowths of quartz and feldspar are well developed between some of the quartz and feldspar grains.
3. Microcline is poikilitic in places.
4. Biotite occurs interstitially to the larger grains of quartz and feldspar.
5. In most places plagioclase is fairly fresh but locally it has been sericitized. In places it is fractured and partially altered to epidote. This alteration has taken place along and away from fractures and resulted in epidote and probably albite.

CLASSIFICATION: Biotite quartz monzonite
Johannsen No. 126"

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4220

Well Name. Delhi Husky Phillips Rock Creek
No. 1

Location. 2-4-10-19-W 3

Sample Depth. 8768 to 8777ft

MEGASCOPIC DESCRIPTION:

Color: f.s. dusky red

Grain size: coarse (5 to 40 mm)

Texture: granitic or pegmatitic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary).

Subhedral inequigranular . Well fractured and locally sheared.
Mutually sutured grain boundaries in places.Mineralogy (minerals are grouped for interpretation; listed in order
of abundance; and whenever possible, percentages estimated)

PRIMARY	METAMORPHIC	ALTERATION
Essential:		
Quartz 50		Chlorite 8.5
Plagioclase An 8 23		Iron oxide 0.2
Microcline 18		Leucoxene tr
		Epidote
Accessory:		INTRODUCED
Apatite tr		
Zircon tr		

SPECIAL FEATURES AND INTERPRETATIONS:

Sp gr = 2.64

1. Quartz is intensely strained, shows well developed sutured boundaries, contains numerous bubble trains, is fractured, and in places fractures have developed into microshear zones along quartz has been broken up. Veinlets of chlorite cut the quartz in places.
2. Microcline is perthitic and contains inclusions of quartz; plagioclase has patch antiperthitic development.
3. The primary mafic minerals have been completely altered to chlorite. The feldspars are coated with iron oxide imparting to them a red color.
4. In general, rock has undergone moderate physical deformation which has produced strained quartz, broken minerals, bent plagioclase twin lamellae, and development of microshear zones throughout the rock. Chemical alteration has produced chlorite.

CLASSIFICATION: Chloritized granite

Johannsen No. 213 (mode indicated above is too high
in quartz)

PETROGRAPHER

Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4221

Well Name. Imperial et al Battle Creek
No. 4-31

Location. 4-31-3-26 W 3

Sample Depth. 7305 ft.

MEGASCOPIC DESCRIPTION:

Color: f.s. light grey

Grain size: fine (average is about 0.5 mm)

Texture: Clastic recrystallized.

MICROSCOPIC DESCRIPTION:

Texture and Structure (primary and secondary)

Anhedral granular. Mosaic of equigranular grains. Some sutured grains boundaries present. Epidote filled fractures.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated).

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Quartz 90 Epidote 9 Carbonate 1	
Accessory		INTRODUCED Some of the epidote is probably introduced.

SPECIAL FEATURES AND INTERPRETATION:

Sp gr = 2.71 Mode by visual estimation.

1. Quartz is slightly strained and contains numerous minute inclusions and bubble trails.
2. Epidote and carbonate are associated in small veinlets throughout the rock. Epidote also occurs dispersed throughout the rock as small grains or clusters of grains.
3. In thin section there is no evidence of the original clastic texture. The quartz forms a solid mosaic of anhedral grains.

CLASSIFICATION: Metaquartzite
Greenschist or
almandine-amphibolite facies.

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4222

Well name. Imperial Good Soil 8-11

Location. 8-11-62-22 W 3

Sample depth. 3460 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. greyish red

Grain size: medium, average 2 mm.

Texture: granitic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary):

Anhedral iquigranular (typical granitic texture).

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:		
Plagioclase An 21 34		Chlorite tr
Quartz 32		Slight alteration on
Microcline 27		plagioclase
Biotite 3.5		
Muscovite 2.0		
Accessory:		INTRODUCED
Mag.-Il. 1.0		
Sphene tr		
Apatite tr		
Zircon tr		

SPECIAL FEATURES AND INTERPRETATION:

Sp gr = 2.66

1. Microcline shows minor development of perthitic intergrowths of the vein type.
2. Plagioclase shows continuous zoning. Sections normal to 010 have a "bullseye" extinction.
3. The rock as a whole is very fresh. The mineralogy and texture are typically igneous.

CLASSIFICATION: Biotite quartz monzonite
Johannsen No. 127"

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA

Sample No. 4223

Well Name. Great Plains McDermott Home
Hay 3-18

Location. 3-18-63-1 W 3

Sample Depth. 2122 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. greyish orange pink

Grain size: medium to coarse, 0.5 to 6 mm

Texture: banded gneissic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary):

Banded, lepidoblastic, porphyroblastic, mostly anhedral. Consists of alternating fine and coarse grained bands. Fine material averages about 0.5 mm and coarse bands range up to 6 mm in grain size. Biotite is concentrated in the finer-grained bands. Secondary features are numerous fractures.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Quartz 30 Orthoclase 20 Biotite 20 Garnet 10	Total alteration- 20 Carbonate Chlorite Sericite Leucoxene Iron oxides Indeterminate material
Accessory:	Zircon tr Apatite tr Sphene tr Mag.-Il. tr	INTRODUCED

SPECIAL FEATURES AND INTERPRETATION:

Sp gr = 2.77

Mode visually estimated.

1. Orthoclase is remarkably fresh considering the altered nature of the whole rock. Twinning and perthitic intergrowths are lacking. Cleavage is well developed. 2V determination indicates that mineral is rather pure orthoclase:

0
2V = 69° (U-stage), composition - Or 93

2. About 15 percent of rock consists of a fine-grained, in part micaceous, mass of material. Some of this material may be the result of shearing but some may be the result of alteration of plagioclase. Much of the material is chlorite and sericite.

CLASSIFICATION: Altered garnet-biotite-quartz-feldspar
gneiss
Upper greenschist or almandine-amphibolite
facies.

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4224

Well Name. Great Plains Montreal Lake 2-5

Location. 2-5-61-24 W 2

Sample depth. 1820 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. greyish black

Grain size: fine (average is about 0.3 mm).

Texture: schistose

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary):

Lepidoblastic to granoblastic inequigranular. Locally diablastic.

Texture is generally lepidoblastic but direction of preferred orientation varies from places to place on the slide. This may be the thin section orientation in part.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated);

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Quartz 41 Biotite 33 Orthoclase 12 Carbonate 7.4 Muscovite 6.0	Kaolinite ? tr
Accessory:	Tourmaline tr Zircon tr Apatite tr Plagioclase ? tr	INTRODUCED Pyrite 0.7 Some carbonate

SPECIAL FEATURES AND INTERPRETATIONS:

Sp gr = 2.77

1. K-feldspar occurs as untwinned, slightly to moderately altered grains of anhedral form. They are generally interstitial to other grains. Identification is based on low index and birefringence

2. Some of the carbonate and most of the pyrite may be introduced because of the occurrence in small veinlets.

3. In places biotite and muscovite have interlayered aggregates of carbonate.

4. Tourmaline is yellowish brown and only basal sections were observed.

CLASSIFICATION: Feldspar-quartz-mica schist
 Upper greenschist or almandine-amphibolite facies.

PETROGRAPHER
 Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4225a

Well Name. Great Plains McDermott Musquash
8-18

Location. 8-18-64-2 W 3

Sample Depth. 2006 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. dark brownish grey

Grain size: fine, average about 0.5 mm

Texture: banded gneissic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary):

Anhedral inequigranular, lepidoblastic.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Quartz 39 Plagioclase An 26 39 Biotite 13 Microcline 9.0	Sericite tr Leucoxene tr Iron oxides tr
Accessory:	Apatite tr Zircon tr	INTRODUCED

SPECIAL FEATURES AND INTERPRETATIONS:

Sp gr = 2.66

1. Plagioclase has poorly developed albite twinning. It is slightly zoned and moderately altered to sericite. Locally antiperthitic intergrowths of the patch type are evident.
2. Microcline is interstitial and poorly twinned.
3. Quartz is strained and occurs as composite elongate grains parallel to the banding and foliation. Sutured quartz grains are common.
4. Where zircon occurs in biotite a very dark halo has developed. The zircon is shattered and probably malakon.

CLASSIFICATION: Biotite-quartz-feldspar gneiss
Almandine-amphibolite facies

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4225b

Well Name. Great Plains McDermott Musquash
8-8

Location. 8-8-64-2 W 3

Sample Depth. 2009 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. black

Grain size: fine, average is about 0.5 mm

Texture: granoblastic, possibly lineated.

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary):

Anhedral equigranular. Simple mosaic of equal sized, straight sided anhedral grains.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible; percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Hornblende 61 Plagioclase An 48 31 Quartz 2.3	Chlorite 1.2 Leucoxene 0.4 Sericite tr
Acessory:	Sphene 2.0 Mag.-Il. 0.8 Pyrite 0.8 Biotite 0.7 Apatite 0.4	INTRODUCED A small vein contains: Quartz Chlorite Hematite Carbonate

SPECIAL FEATURES AND INTERPRETATION:

Sp gr = 3.02

- Hornblende--large 2V (-), pleochroic formula: X = dark green
Y = greenish brown
Z = light tan
- There is no evidence of any preferred orientation in thinsection although a poorly developed lineation is suggested in hand specimen.
- Plagioclase is moderately altered to sericite.
- Chlorite has altered from both biotite and hornblende.

CLASSIFICATION: Plagioclase amphibolite
Almandine-amphibolite faciesPETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4225c

Well Name. Great Plains McDermott Musquash

Location. 8-8-64-2 W 3

Sample Depth. 2017 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. dark reddish brown

Grain size: fine to medium

Texture: gneissic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary):

Anhedral inequigranular. Foliation not evident in thin section.

Many grains have sutured boundaries.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Microcline 35 Quartz 31 Plagioclase An 28 30	Chlorite 0.1 Sericite tr Carbonate tr Iron oxides tr
Accessory	Biotite 1.7 Apatite tr Zircon tr	INTRODUCED Carbonate 1.4 in veinlet.

SPECIAL FEATURES AND INTERPRETATIONS:

Sp gr = 2.63

1. Quartz is intensely strained and contains numerous bubble trains and minute inclusions.
2. Microcline has well developed grid-iron twinning and is moderately perthitic.
3. Alteration of plagioclase varies from nil to places where sericite and carbonate are strongly developed on the plagioclase.
4. Individual and composite grains are oriented in the direction of foliation.

CLASSIFICATION: Biotite-quartz-feldspar gneiss
 Almandine-amphibolite facies

PETROGRAPHER
 Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4225d

Well Name. Great Plains McDermott Musquash

Location. 8-8-64-2 W 3

Sample Depth. 2026 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. dark greyish red

Grain size: medium, 1 to 5 mm

Texture: gneissic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary):

Anhedral inequigranular. Some grains have sutured boundaries and mortar structures are present surrounding some of the larger grains.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Plagioclase An 27 40 Quartz 29 Microcline 27 Biotite 3.6	Chlorite tr Sericite tr Iron oxide tr
Accessory:	Zircon tr Sphene tr	INTRODUCED Carbonate veinlets

SPECIAL FEATURES AND INTERPRETATIONS:

Sp gr = 2.64

1. Microcline shows minor vein perthite development.
2. Plagioclase is antiperthitic and partially altered to sericite in places.
3. Quartz is intensely strained and locally fractured. Sutured contacts are common.

CLASSIFICATION: Biotite-quartz-feldspar gneiss
Almandine-amphibolite facies

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4226

Well Name. Great Plains Smoothstone 1-36

Location. 1-36-63-5 W 3

Sample Depth. 1921 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. blackish red

Grain Size: medium to coarse; groundmass, 1 to 2 mm; porphyroblasts, 10-15 mm

Texture: porphyroblastic gneissic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary):

Anhedral inequigranular--porphyroblastic

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential;	Plagioclase An 32 42 Quartz 22 Microcline 21 Biotite 8.6 Hornblende 4.3	Leucoxene 1.3 Chlorite 0.3 Carbonate 0.2 Sericite tr
Accessory:	Apatite 0.4 Mag.-Il. 0.3 Sphene tr	INTRODUCED

SPECIAL FEATURES AND INTERPRETATION:

Sp gr = 2.71

1. The porphyroblastis are non-perthitic, poikiloblastic microcline with inclusions of quartz, plagioclase, and biotite. The K-feldspar in the groundmass is untwinned and very fresh.

2. Minor myrmekite has developed at quartz-feldspar contacts.

3. Hornblende in places has partially altered to chlorite, carbonate, and sericite. Alteration is most intensely developed at cleavages.

CLASSIFICATION: Hornblende-biotite-quartz-feldspar gneiss
 Almandine-amphibolite facies

PETROGRAPHER
 Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4227a, 4227b
 Well Name. Great Plains McDermott West
 Montreal Lake 5-22

Location. 5-22-62-26 W 2
 Sample Depth. 4227a; 1851 ft
 4227b; 1855 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. light olive grey (both samples)
 Grain size: fine to medium (4227a); fine (4227b)
 Texture: banded gneissic (both samples)

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary):

4227a: anhedral inequigranular, large grains of quartz to 5 mm in dia
 suspended in a fine-grained groundmass. Fractured and sheared.

4227b: anhedral inequigranular, lepidoblastic. Quartz and biotite averaging
 0.3 mm in dia suspended in a finer-grained groundmass.

Mineralogy (minerals are grouped for interpretation; listed in order of
 abundance; and whenever possible percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential;	4227a: Quartz 30 Biotite 5 4227b: Quartz 15 Biotite 25 K-feldspar ?	4227a: Carbonate 25 Chlorite) Leucoxene (40 Iron oxides) Groundmass (40 4227b: Carbonate 5 Indeterminate groundmass 55
Accessory:	4227a: Apatite tr Mag.-Il. tr 4227b: Apatite tr Garnet tr	INTRODUCED

SPECIAL FEATURES AND INTERPRETATIONS:

Sp gr (indeterminate for both samples)

4227a:

1. The groundmass is a fine-grained aggregate of low birefringent minerals with negative relief. Positive optical identification is impossible.
2. In places biotite is very fresh but elsewhere it is partially altered to chlorite and in places interlayered with carbonate. Iron oxides are associated with clusters of biotite.
3. Quartz grains have been severely fractured and carbonate has been deposited along these fractures in places.

4227b:

1. Biotite is relatively fresh in spite of the altered nature of the total rock.
2. Groundmass is the same as 4227a.

CLASSIFICATION: Altered quartz-biotite gneiss (both)
 Upper greenschist or almandine-
 amphibolite facies.

PETROGRAPHER
 Zell Peterman

270
PETROGRAPHIC DESCRIPTION

FIELD DATA

Sample No. 4228
Well Name. Imperial California Standard
Ft. a la Corne 8-9

Location. 8-9-50-18 W 2
Sample Depth. 2378 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. medium light grey
Grain size: fine, 0.05 to 0.1 mm
Texture: Clastic, schistose

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary):

Two phases are present in core--greywacke and phyllite. Following description is of the greywacke phase. Phyllite is similar to the greywacke matrix.

Sedimentary clastic texture well preserved. Angular to subangular grains as large as 0.5 mm of quartz and feldspar suspended in a recrystallized matrix.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY		METAMORPHIC		ALTERATION
Essential (detrital)		Matrix:		
Quartz	50	Biotite	10	
Microcline		Quartz	15	
Plagioclase)	20	Feldspar?)		
		Sericite	5	
		Opagues	tr	
		Carbonate	tr	
Accessory (detrital)				INTRODUCED
Tourmaline	tr			
Apatite	tr			
Zircon	tr			
Muscovite	tr			

SPECIAL FEATURES AND INTERPRETATIONS:

Sp gr = 2.35 (total core, greywacke + phyllite), Mode visually estimated.

1. Microcline is the dominant feldspar and it is very fresh. Only a few grains of plagioclase are present in the thin section.
2. No definite rock fragments were noted but a few composite grains of quartz are present.
3. The clastic nature of the rock has survived the low grade metamorphism. The matrix is recrystallized.

CLASSIFICATION: Arkosic metagreywacke
Greenschist facies

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4229

Location. 9-32-6-22 W 3

Well Name. Mobil Woodley Southern Dorrell 32-9

Sample Depth. 8820 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. greyish red

Grain Size: medium, 1 to 5 mm

Texture: granitic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary):

Anhedral inequigranular. Average grain size is about 3mm but range is from 1 to 5 mm. Sutured grain boundaries present.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:		
Microcline 43		Chlorite 3.0
Plagioclase An 4 33		Epidote 1.7
Quartz 20		Leucoxene tr
		Iron oxide tr
Accessory:		INTRODUCED
Biotite 1.5		Carbonate in small veins
Mag.-Il 1.4		
Apatite tr		
Muscovite tr		
Zircon tr		

SPECIAL FEATURES AND INTERPRETATIONS:

Sp gr = 2.63

1. Sutured grain boundaries, undulatory extinctions in quartz, and warped twin lamellae of plagioclase are common secondary features.
2. Plagioclase is moderately altered and stained with iron oxide.
3. Microcline has rare perthitic intergrowths and is poikilitic in places.
4. Biotite has been extensively altered to chlorite.

CLASSIFICATION: Granite
Johanssen No. 216"

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4230

Location 15-3-17-18 W 3

Well Name. Mobil Woodley Southern Fosterton 15-3

Sample Depth. 7258 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. brownish black

Grain size: fine to coarse

Texture: porphyritic, granitic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary):

Anhedral equigranular groundmass (1 to 2 mm grain size).

Subhedral phenocrysts (5 to 20 mm grain size)

Phenocrysts are typically rounded.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:		
Microcline 34		Chlorite 0.5
Granophyre 24		Leucoxene tr
K-feldspar (12)		Epidote tr
Quartz (12)		
Quartz 18		
Plagioclase An 5 11		
Biotite 8.7		
Totals:		
Microcline 46		
Quartz 30		
Accessory:		INTRODUCED
Mag.-Il 1.2		
Sphene 1.0		
Hornblende 0.5		
Apatite 0.2		
Zircon tr		
Muscovite tr		

SPECIAL FEATURES AND INTERPRETATIONS:

Sp gr = 2.67

1. Phenocrysts are microcline, plagioclase, and quartz. Microcline phenocrysts are the most abundant. Total phenos. form about 50 percent of the rock.
2. Microcline is perthitic in both the phenocrysts and the graphic intergrowths. The microcline phenocrysts are poikilitic and contains inclusions of all of the the other minerals.
3. Plagioclase is moderately altered and very complexly twinned.
4. Quartz is strained and in places contains small microlites. As individual grains the quartz is typically rounded as are the other phenocrysts.
5. Granophyre occurs interstitially and is especially well developed along the boundaries of the microcline phenocrysts.
6. The mafic minerals are commonly associated in clots or clusters throughout the rock.

CLASSIFICATION: Porphyritic granophyric granite
Johannsen No. 216"

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4231 b
Well Name. Mobil North Richmond 31-1

Location. 1-31-18-28 W 3
Sample Depth. 7424 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. greenish black
Grain size: Fine (clay size to 2 mm)
Texture: poorly foliated

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary):
Original texture was probably banded gneissic. Subangular grains of quartz; and biotite occur in a fine-grained groundmass. Quartz grains show preferred orientation and are localized in thin bands. Intense shearing has been accompanied by chemical alteration.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Quartz 20 Biotite 15	Chlorite) Iron oxides (10 Carbonate) Leucoxene (Indeterminate fine-grained groundmass 55
Accessory:	Apatite tr Zircon tr Mag.-Il. tr	INTRODUCED

SPECIAL FEATURES AND INTERPRETATIONS:

Sp gr = 2.77 Mode visually estimated.

1. The rock is composed of fractured and strained quartz grains, partially altered biotite, and minor accessories suspended in a fine-grained groundmass of low-birefringent minerals.

2. Biotite is green but has high birefringence. It is interlaminated with red iron oxide and in places shows a bow-tie structure where the ends of the grains have expanded due to alteration.

3. Carbonate is associated with the iron oxides and green biotite.

CLASSIFICATION: Chlorite-biotite schist (propylite)
Greenschist facies

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4231 d
Well Name. Mobil North Richmond 31-1

Location. 1-31-18-28 W 3
Sample Depth. 7440 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. greenish black
Grain Size: fine (average about 0.5 mm)
Texture: faintly gneissic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary):

Anhedral inequigranular, lepidoblastic. Mafic minerals are concentrated in a crude thin banding. In the non-banded parts the texture is an anhedral mosaic.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Plagioclase An 32 56 Quartz 15 Hornblende 14 Biotite 12	Chlorite 1.6 Sericite 0.8 Epidote tr Carbonate tr
Accessory:	Mag.-Il. 0.6 Zircon tr Apatite tr	INTRODUCED

SPECIAL FEATURES AND INTERPRETATIONS:

Sp gr = 2.77

1. Plagioclase is well to poorly twinned. Locally, alteration has produced sericite and epidote.
2. The quartz is generally finer grained than the plagioclase. All of the quartz grains are markedly strained.
3. Biotite and hornblende are typically associated in crude bands. Biotite fresh and hornblende has altered to chlorite and carbonate in places. Some of the hornblende grains are poikiloblastic with numerous quartz inclusions.
4. Apatite grains are typically rounded and zircon are dark and shattered.

CLASSIFICATION: Biotite-hornblende-quartz-andesine gneiss PETROGRAPHER
Almandine-amphibolite facies Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4232

Well Name. Mobil von Mehren Lake 8-15

Location. 8-15-52-2 W 3

Sample Depth. 3290 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. dark brownish grey

Grain Size: medium to coarse; groundmass, 1 to 2 mm; porphyroblasts, to 10 mm

Texture: gneissic porphyroblastic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary):

Anhedral inequigranular, gneissic, porphyroblastic. (porphyroblastic texture was not seen in this thin section)

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Plagioclase An 28 40 Quartz 24 Microcline 18 Biotite 15	Sericite 1.4 Carbonate 1.4 Chlorite 0.4 Leucoxene 0.2
Accessory:	Apatite 0.6 Zircon tr Sphene tr	Introduced

SPECIAL FEATURES AND INTERPRETATIONS:

Sp gr = 2.66

1. Plagioclase is slightly to moderately altered to sericite and in places contains numerous inclusions of iron oxide. It is antiperthitic of the patch variety.
2. Microcline is poorly twinned and has vein-type perthitic intergrowths
3. Minor myrmekite is present.
4. Biotite has partially altered to chlorite, leucoxene, and carbonate. The carbonate commonly occurs as elongate lenses interlayered with the biotite.

CLASSIFICATION: Biotite-quartz-feldspar gneiss
 Almandine-amphibolite facies.

PETROGRAPHER
 Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4233

Well Name. Red River Hepner No. 2

Location. 2-1-5-2 W 1

Sample Depth. no known

MEGASCOPIC DESCRIPTION:

Color: f.s. medium dark grey

Grain size: fine (average 1 to 2 mm)

Texture: gneissic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary)

Anhedral inequigranular, lepidoblastic (banding not evident in thin section). Grains range up to 5 mm in size.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Plagioclase An 32 48 Quartz 31 Biotite 13 Microcline 5.5	Chlorite 1.0 Carbonate tr Leucoxene tr
Accessory:	Epidote 0.8 Muscovite 0.7 Apatite tr Sphene tr Zircon tr Mag.-Il. tr	INTRODUCED

SPECIFIC FEATURES AND INTERPRETATIONS:

Sp gr = 2.68

1. Locally plagioclase is strongly altered to sericite, carbonate, and epidote. Twin lamellae are deformed in places.

2. Biotite is partially altered to chlorite and granular sphene.

3. Quartz is moderately strained.

4. Microcline commonly occurs as small grains interstitial to the main constituents.

5. Zircon is rounded, fractured, and looks metamict.

CLASSIFICATION: Biotite-quartz-andesine gneiss
 Almandine-amphibolite facies

PETROGRAPHER
 Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4234

Well Name. Socony Western Prairie Imperial
Carievale No. 1

Location. 16-4-3-32 W 1

Sample Depth. 8328 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. pale reddish brown

Grain size: Fine, average about 1mm

Texture: granitic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary)

Anhedral equigranular.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:		
Quartz 37		Carbonate tr
Plagioclase An 25 33		Iron oxide tr
Microcline 26		Chlorite tr
Biotite 2.9		
Accessory:		INTRODUCED
Muscovite 0.8		
Zircon tr		
Sphene tr		

SPECIAL FEATURES AND INTERPRETATIONS:

Sp gr = 2.63

1. Plagioclase is slightly zoned and in places the more calcic is slightly altered and rimmed with more sodic, completely fresh plagioclase.

2. Microcline has a strong development of perthitic intergrowths.

3. Quartz is moderately strained and contains numerous bubble trails and minute inclusions.

CLASSIFICATION: Biotite quartz monzonite
Johannsen No. 127"

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4235

Well Name. Stony Mountain No. 1

Location. 7-29-12-2 E 1

Sample Depth. not known

MEGASCOPIC DESCRIPTION:

Color: f.s. medium light grey

Grain size: fine, average about 1 mm, range 0.2 to 2 mm

Texture: gneissic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary):

Anhedral inequigranular, lepidoblastic. Sutured grain boundaries are common.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Plagioclase An 24-30 49 Quartz 28 Microcline 14 Biotite 6.0	Chlorite tr
Accessory:	Hornblende 0.8 Epidote 1.9 Sphene 0.7 Mag.-Il. tr Apatite tr	INTRODUCED

SPECIAL FEATURES AND INTERPRETATIONS:

Sp gr = 2.68

1. Plagioclase is normally zoned from An 30 to An 24. Zoning is continuous.
2. Microcline is perthitic of the vein type and minor myrmekite is present.
3. Strained quartz grains and sutured grain boundaries are common.
4. Typical mafic association is biotite, epidote, hornblende, and sphene.
5. Sphene occurs as well formed crystals up to 1.5 mm in length.

CLASSIFICATION: Biotite-quartz-feldspar gneiss
 Almandine-amphibolite facies.

PETROGRAPHER
 Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No.: 4236

Well Name. Tidewater Stalwart No. 1

Location. 14-10-27-25 W 2

Sample Depth. 5955 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. dusky red

Grain size: medium, average is 1 mm +, range is 0.5 to 2 mm.

Texture: granitic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary):

Anhedral granular. Fractured.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:		
Plagioclase An 25 63		Carbonate tr
Quartz 32		Chlorite tr
Microcline 3.7		Iron oxide tr
		Sericite tr
Accessory:		INTRODUCED
Mag.-Il. 1.7		
Biotite 0.1		
Muscovite 0.1		

SPECIAL FEATURES AND INTERPRETATIONS:

Sp gr = 2.55

1. Red coloration is due to iron oxide staining associated mainly with the plagioclase.
2. Plagioclase is severely altered to sericite.
3. Quartz is strained, fractured, and lined with bubble trains and other inclusions
4. Chlorite occurs as fibrous mass and in places is associated with carbonate.

CLASSIFICATION: Altered granodiorite
Johannsen No. 127

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4237

Well Name. Triad Whitefox 12-15

Location. 12-15-52-14 W 2

Sample Depth. 1785 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. brownish black

Grain size: fine, 0.2 to 0.5 mm

Texture: schistose

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary)

Anhedral granular (lepidoblastic texture not well shown in thin section because of orientation of thin section slice). Cordierite shows poikiloblastic texture.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential;	Biotite 38 Quartz 28 Plagioclase An 32 14 Cordierite 13 Sillimanite 4.6	Slight alteration of cordierite to indeterminate isotropic mineral.
Accessory:	Pyrite 1.0 Garnet 0.6 Apatite tr Zircon tr	INTRODUCED

SPECIAL FEATURES AND INTERPRETATIONS:

Sp gr = 2.80

1. Cordierite is poikiloblastic and contains numerous rod-like inclusions which are probably sillimanite. Alteration to isotropic mineral occurs mainly at the grain boundaries and along fractures within the grains.

2. Biotite is pleochroic in shades of reddish brown. Probably iron rich.

CLASSIFICATION: Cordierite-quartz-biotite schist
 Sillimanite-almandine subfacies
 of the almandine-amphibolite facies.

PETROGRAPHER
 Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4238

Well Name. Triad Whitefox 13-18

Location. 13-18-52-13 W 2

Sample Depth. 1615 ft

MEGASCOPIC DESCRIPTION:

Color:f.s. brownish grey

Grain Size: fine to coarse

Texture: banded gneissic (very coarse-grained pegmatitic phase parallel to banding not in thin section.)

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary):

Grain size of thin section slice varies from 0.1 to 0.8 mm.

Anhedral inequigranular. Some sutured grain boundaries. Foliation and banding not evident in thin section.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential;	Plagioclase An 27 42 Quartz 33 Microcline 16 Biotite 5.4 Muscovite 2.6	Sericite tr Chlorite tr
Accessory:	Zircon tr Apatite tr	INTRODUCED

SPECIAL FEATURES AND INTERPRETATIONS:

Sp gr = 2.64

1. Some of the larger plagioclase grains contain small elongate foils of sericite or muscovite oriented parallel to 010 and 001 cleavage directions. The smaller grains are free of these oriented inclusions but some contain sericite as alteration products. Some grains are completely free of any alteration. Some of the plagioclase grains are continuously zoned. The larger grains also contain rounded quartz inclusions.
2. Both perthitic and non-perthitic microcline is present.
3. The larger grains of muscovite and biotite are in places associated and muscovite cross-cuts the biotite.

CLASSIFICATION: Biotite-quartz-feldspar gneiss
Almandine-amphibolite facies

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4483

Well Name. Imperial Stoughton 3-27

Location. 3-27-8-8 W 2

Sample Depth. 8830 ft

MEGASCOPIC DESCRIPTION:

Color:f.s. light grey

Grain Size: medium, average is 3 mm, ranges up to 5 mm.

Texture: faintly gneissic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary):

Anhedral inequigranular. Poikiloblastic in places.

Sutured grain boundaries common.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated)

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Quartz 45 Microcline 29 Plagioclase 14 Cordierite 10	Cordierite altered to: 1. unknown isotropic mineral 2. sericite 3. carbonate 4. leucoxene ?
Accessory:	Biotite 0.2 Sericite 1.3 Zircon tr	INTRODUCED

SPECIAL FEATURES AND INTERPERATIONS:

Sp gr = 2.58

1. Quartz shows intense straining and is locally fractured. In places it is poikiloblastic with inclusions of cordierite. Some quartz grains about 5 mm in diameter.

2. Microcline is well twinned and perthitic.

3. Plagioclase shows effects of straining by undulatory extinction and bent twin lamellae.

4. Cordierite is commonly rounded and alteration to an isotropic mineral has occurred at the boundaries of the grains and along fractures within the grains.

CLASSIFICATION: Cordierite-quartz-feldspar gneiss
 Almandine-amphibolite facies,
 transitional from hornblende hornfels

PETROGRAPHER
 Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4484

Well Name. Irex C-11-3

Location. 11-3-50-18 W 2

Sample Depth. 3056 ft

MEGASCOPIC DESCRIPTION:

Color:f.s. dark grey

Grain size: fine (0.1 to 0.2 mm)

Texture : thinly banded foliated

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary)

Anhedral equigranular. Alternating bands of light and dark minerals range in width from 1 to 3 mm. Banding is probably primary compositional.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Quartz (includes minor feldspar) 32 Magnetite 51 Biotite 8.3 Carbonate 5.5 Amphibole 3.3	
Accessory:	Muscovite tr	INTRODUCED

SPECIAL FEATURES AND INTERPRETATIONS:

Sp gr = 3.49

1. Main features of the rock are the well developed fine banding and complete lack of any alteration.
2. Amphibole is pleochroic in shades of greenish blue and shows anomalous blue interference colors. May be riebeckite.

CLASSIFICATION: Iron formation (biotite-quartz-magnetite
schist or gneiss)
Almandine-amphibolite facies

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4485b
Well Name. Irex D-12-3

Location. 12-3-50-18 W 2
Sample Depth, 3170 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. dark grey
Grain size: fine, 0.1 to 1 mm
Texture: banded gneissic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary)

Anhedral granular and lepidoblastic. Crudely banded and bands are contorted. Different bands are dominated by carbonate; quartz and biotite; and biotite.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Carbonate 40 Biotite 23 Quartz 31 Plagioclase 4.1	Chlorite tr
Accessory	Tourmaline 0.6 Magnetite 0.4	INTRODUCED

SPECIAL FEATURES AND INTERPRETATIONS:

Sp gr = 2.88

1. Much of the plagioclase is poorly twinned and may have been counted as quartz.
2. Carbonate occurs as larger than average grains, generally from 0.5 to 1mm, and forms a simple mosaic intergrowth. Some grains are strained.
3. One band is composed completely of biotite.

CLASSIFICATION: Biotite-quartz marble or
Biotite-quartz-carbonate gneiss
Probably almandine-amphibolite
facies

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4485 c
Well Name. Irex D-12-3

Location. 12-3-50-18 W 2
Sample Depth. 3217 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. dark grey
Grain size: fine (0.1 to 0.2 mm)
Texture: thinly banded foliated

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary)

Anhedral equigranular, banded and locally lepidoblastic. Alternating bands are quartz-rich and magnetite-rich and average about 0.5 mm in width.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated)

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Quartz 43 Magnetite 31 Biotite 20 Carbonate 6.4	
Accessory:		INTRODUCED

SPECIAL FEATURES AND INTERPRETATIONS:

Sp gr = 3.25

1. There may be some plagioclase present but if so it is untwinned and not distinguishable from quartz.
2. Magnetite occurs as subhedral to anhedral grains commonly concentrated in very narrow bands and in places associated with brownish green biotite.
3. Rock is characterized by simple mineralogy and lack of alteration.

CLASSIFICATION: Biotite-magnetite-quartz schist
Probably almandine-amphibolite facies.

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4677

Well Name. White Rose St. Denis

Location. 4-16-37-1 W 3

Sample Depth. 5406 to
5410 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. very dusky red

Grain size: fine (average about 1 mm)

Texture: gneissic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary):

Anhedral inequigranular, lepidoblastic. Mortar structures. All essential minerals show effects of straining.

Sutured grain boundaries are common.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:	K-feldspar 38 Quartz 31 Plagioclase An 30 24 Biotite 5.0	Carbonate 1.0 Chlorite 0.4 Epidote tr Iron oxides tr
Accessory:	Pyrite) Mag.-Il.) 0.8 Apatite 0.4 Zircon tr	INTRODUCED

SPECIAL FEATURES AND INTERPRETATIONS:

Sp gr = 2.66

1. Quartz occurs as elongate anhedral oriented parallel to the foliation. It exhibits marked undulatory extinction and is locally fractured.
2. K-feldspar is probably microperthitic orthoclase. Grid-iron twinning is not evident.
3. Plagioclase is moderately altered. In places antiperthite of the patch variety is developed.
4. The light to dark reddish brown biotite is typically associated with chlorite and carbonate.
5. Apatite is abundant as an accessory and occurs as subhedral grains. One grain of apatite is mantled with epidote which in contains two small zircon crystals.
6. Zircon is partially to completely metamict and commonly rounded.
7. Pyrite and magnetite are associated with biotite.

CLASSIFICATION: Biotite-quartz-feldspar gneiss
Almandine-amphibolite facies

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No: 4678

Well Name: Amerada Unit A Antelope

Location: Sec 1, T. 159 N., R. 95W

Sample Depth: 15,128 ft

MEGASCOPIC DESCRIPTION:

Color: f.s. dark grey

Grain size: fine

Texture: granular

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary)

Anhedral granular. Some sutured grain boundaries, strained and bent minerals common.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated)

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Plagioclase An 30 32 Microcline 30 Quartz 25 Hypersthene 5.8	Chlorite 2.0 Carbonate 0.4 Iron oxide tr Sericite tr
		INTRODUCED
Accessory:	Biotite 1.4 Hornblende 1.2 Mag.-Il. 1.4 Apatite 0.6 Zircon tr	

SPECIAL FEATURES AND INTERPRETATION:

Sp gr = 2.72

1. Most of the minerals are strained and in places are considerably deformed.
2. Plagioclase is fairly fresh and well twinned and in places the twin bands are bent.
3. Quartz forms composite grains in places and has sutured grain boundaries.
4. Microcline is strongly perthitic of the vein type.
5. Hypersthene is fresh in most places but locally it is broken and altered.
6. Hornblende and biotite are associated with hypersthene and probably altered from it.
7. Apatite and zircon are abundant as accessories and both are rounded. Zircon is partially metamict.

CLASSIFICATION: Hypersthene-quartz-feldspar granulite
 Pyroxene granulite facies

PETROGRAPHER
 Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4679

Well Name. Amerada No. 1 Iverson Nelson Unit

Location. Sec. 2, T.155 N.
R. 96 W.

Sample Depth. 13,603 ft

MEGASCOPIC DESCRIPTION:

Color: greyish red

Grain size: medium

Texture: granitic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary)

Highly altered but original textures was probably subhedral granular. Subhedral to euhedral lathes of perthitic orthoclase are randomly oriented and form the main framework of the rock. These occur to a maximum length of 5 mm and 2 to 3 mm in width.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated)

PRIMARY	METAMORPHIC	ALTERATION
Essential:		
Perthitic orthoclase 30		Sericite 30 Chlorite 30 Muscovite 5 Carbonate 5 Iron oxides tr
Accessory:		INTRODUCED
Hornblende tr		
Biotite tr		

SPECIAL FEATURES AND INTERPRETATIONS:

Sp gr = 2.72

1. Severe chemical alteration has left only the perthitic orthoclase relatively unaltered. One of the main constituents has been altered completely to sericite.
2. Chlorite and hematite or iron oxides are abundant alteration products. From the rounded form of some of the chlorite-hematite pseudomorphs, the original mineral could have been olivine.
3. The rock has not been physically altered to any extent.

CLASSIFICATION: Altered syenite

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4680

Well Name. Herman Hanson No. 1 Mueller

Location. Sec. 20, T.140 N.
R.65 W.

Sample Depth. not known

MEGASCOPIC DESCRIPTION:

Color:f.s. greyish pink

Grain size: fine (ranges from 0.5 to 1.0 mm)

Texture: granitic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary)

Anhedral granular. Mosaic of quartz and feldspar. Slight lineation or foliation is due to elongation of quartz grains. This does not appear in thin section.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:		
Microcline 35		Sericite tr
Quartz 30		Carbonate tr
Plagioclase An 28 30		Iron oxides tr
Accessory:		INTRODUCED
Biotite 2.1		
Mag.-Il. 1.8		
Muscovite 1.2		
Apatite tr		

SPECIAL FEATURES AND INTERPRETATIONS:

1. Quartz is moderately strained, in places composite, and shows sutured grain boundaries.
2. Slightly perthitic microcline is fresh and well twinned.
3. Plagioclase is moderately altered to sericite and possibly kaolinite. It is locally zoned.
4. Biotite and magnetite-ilmenite grains are partially altered to hematite or other secondary iron oxides.

CLASSIFICATION: Biotite quartz monzonite
Johannsen No. 126"

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4681

Well Name. Carter Northern Ordnance No. 1

Location. Sec. 35, T.133 N.
R. 75 W.

Sample Depth. not known

MEGASCOPIC DESCRIPTION:

Color:f.s. dark grey

Grain size: fine, average about 0.5 mm

Texture: gneissic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary)

Anhedral granular with lepidoblastic biotite.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Plagioclase An 23 56 Quartz 30 Biotite 8.8 Epidote 3.6	
Accessory:	Sphene 0.4 Apatite 0.4 Hornblende 0.4 Pyrite 0.4 Zircon tr Carbonate tr	INTRODUCED

SPECIAL FEATURES AND INTERPRETATIONS:

Sp gr = 2.73

1. Plagioclase is completely fresh and well twinned. Typically occurs as anhedral, equil-sized grains. Slightly zoned continuously.

2. Quartz is slightly strained.

3. Biotite is associated with epidote and other accessories.

CLASSIFICATION: Epidote-quartz-biotite-feldspar gneiss
Almandine-amphibolite facies

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4682
Well Name. Union Oil No. 1 Skjervheim

Location. Sec. 28, T.159 N.,
R.63 W.
Sample Depth. 3408 ft

MEGASCOPIC DESCRIPTION:

Color:f.s. dark grey
Grain size: medium, 1 to 2 mm
Texture: gneissic (large segregation of quartz in hand specimen)

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary)

Anhedral inequigranular. Foliation not evident in thin section. Mortar structure around some of the larger grains.

Mineralogy (minerals are grouped for interpretation; listed in order of abundances; and whenever possible percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Plagioclase An 27 50 Quartz 35 Microcline 4.4 Biotite 6.6	Chlorite 1.8 Sericite 0.2 Carbonate 0.2 Sphene tr
Accessory:	Pyrite-Pyrr. 0.6 Epidote 0.4 Zircon 0.2 Apatite 0.2	INTRODUCED

SPECIAL FEATURES AND INTERPRETATIONS:

Sp gr = 2.66

1. Plagioclase is moderately altered to sericite and in places, epidote.
2. Quartz is strained and composite in places.
3. In places biotite has been altered to chlorite and granular sphene.
4. Apatite and zircon are abundant as accessories. Zircon is partially metamict.
5. The opaques and most of the epidote are associated with biotite and chlorite.

CLASSIFICATION: Biotite-quartz-feldspar gneiss
Almandine-amphibolite facies

PETROGRAPHER
Zell. Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4498 a
Collector. G. S. Barry

Location. 54° 32'N., 94° 30'W.
: Gods Narrows, Gods
Lake, Manitoba
Occurrence. Post-Oxford group
intrusion

MEGASCOPIC DESCRIPTION:

Color:f.s. light grey
Grain size: fine, average about 0.5 mm
Texture: gneissic, faintly banded

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary)

Anhedral inequigranular. Microcline is poikiloblastic. No foliation or banding evident in thin section.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible percentages estimated)

PRIMARY	METAMORPHIC	ALTERATION
Essential:		
Plagioclase An 23 51		Chlorite 0.6
Quartz 23		Sericite tr
Biotite 12		Leucoxene tr
Microcline 11		
Accessory:		
Epidote 0.6		
Mag.-Il. 0.4		
Apatite 0.2		
Sphene tr		
Zircon tr		
Pyrite tr		
Muscovite 1.0		

SPECIAL FEATURES AND INTERPRETATION:

1. Plagioclase is strongly altered to sericite in places but is locally fresh. Some grains contain small grains of epidote. Twinning is poorly developed and some grains may be continuously zoned.
2. Microcline appears to be porphyroblastic as it contains many inclusions of other minerals and occurs in a larger than average grain size (maxium 2 mm).
3. Quartz is strained and occurs in composite masses forming a mosaic texture.
4. Mortar structure has developed around some of the larger grains. These grains are rounded and rimmed with finer grained quartz, feldspar, and micas.
5. On petrographic evidence alone the rock would be classed as metamorphic but field evidence indicates its intrusive relationships to the Cross Lake group of metasediments.

CLASSIFICATION: Gneissic granodiorite (Biotite-quartz-feldspar gneiss) PETROGRAPHER Zell Peterman
Johannsen No. 227

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4498 b
Collector. G. S. Barry

Location. 54° 38'N., 94° 30'W.
Gods Narrows, Gods Lake
Manitoba

Occurrence. Pre-Oxford group
intrusion (post-Hayes
River group)

MEGASCOPIC DESCRIPTION:

Color:f.s. light grey
Grain size: medium, 1 to 2 mm
Texture: granitic

MICROSCOPIC DESCRIPTION

Texture and structure (primary and secondary)

Subhedral granular. The texture is typically igneous. Euhedral to subhedral grains of plagioclase form the main framework with anhedral grains of quartz. The remaining minerals are dispersed throughout this framework in a nonoriented fashion.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:		
Plagioclase An 36 59		Leucoxene tr
Quartz 25		Chlorite tr
Microcline 8.3		Epidote tr
Biotite 4.3		Sericite tr
Hornblende 2.9		
Accessory:		INTRODUCED
Mag.-Il.-Pyrr. 0.6		
Sphene 0.4		
Zircon tr		
Apatite tr		

SPECIAL FEATURES AND INTERPRETATIONS:

1. Plagioclase shows marked oscillatory zoning. Most grains are relatively unaltered.
2. Quartz forms composite grains with mosaic texture. Some grains show straight extinction and others are slightly strained. A few grains are fractured but still in optical continuity.
3. Microcline forms interstitial anhedral grains in places showing perthitic intergrowths.
4. Biotite is olive brown and contains numerous small needle-like crystals.
5. Sphene is abundant as an accessory and forms anhedral grains.

CLASSIFICATION: Hornblende-biotite granodiorite
Johannsen No. 227

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4499a
Collector. D. H. Rousell

Location. 54° 38'N., 97° 47'W.
Cross Lake, Manitoba
Occurrence. Older gneissic
complex (pre-Cross
Lake group)

MEGASCOPIC DESCRIPTION:

Color: f.s. brownish grey
Grain size: medium, 1 to 3 mm
Texture: gneissic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary)

Anhedral granular, lepidoblastic. Main framework is granular with lepidoblastic micas.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Plagioclase An 21 45 Quartz 24 Microcline 13 Biotite 11 Epidote 4 Muscovite 3	Leucoxene tr
Accessory:	Sphene 0.4 Apatite tr Mag.-Il. tr	

SPECIAL FEATURES AND INTERPRETATION:

1. Anhedral to subhedral plagioclase grains form the largest grains of the rock. In places plagioclase grains contain sub-oriented inclusions of epidote and muscovite. Poorly twinned.
2. Quartz is intensely strained and where several grains are in contact they are mutually sutured.
3. Microcline is completely fresh and has well developed perthitic intergrowths.
4. Olive brown biotite contains some inclusions of sphene and other small grains which are surrounded by pleochroic halos.
5. Epidote-sphene-biotite is a typical association.

CLASSIFICATION: Biotite-quartz-feldspar gneiss
Almandine-amphibolite facies

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4499 b
Collector. D. H. Rousell

Location. 54° 36'N., 97° 56'W.
Cross Lake, Manitoba
Occurrence. Post-Cross Lake
group intrusion.

MEGASCOPIC DESCRIPTION:

Color:f.s. medium dark grey
Grain size: medium, 1 to 3 mm
Texture: granitic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary)

Anhedral inequigranular. Some mortar structure.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated)

PRIMARY	METAMORPHIC	ALTERATION
Essential:		
Plagioclase An 21 47		Leucoxene tr
Quartz 35		Chlorite tr
Biotite 8		
Microcline 5		
Epidote 3		
Muscovite 2		
Accessory:		INTRODUCED
Apatite 0.4		
Sphene tr		
Zircon tr		

SPECIAL FEATURES AND INTERPRETATIONS:

1. Plagioclase forms crystals larger than average size, up to 5 or 6 mm. In places it is poikilitic with inclusions of quartz, microcline, and biotite.
2. Quartz occurs as composite grains with sutured contacts and undulatory extinction. In places bubble trains are continuous through the composite mosaics.
3. Unaltered microcline is strongly perthitic. In contact with plagioclase there are locally, rims of albite separating the two minerals.
4. Biotite is slightly altered to chlorite in places.
5. Epidote is abundant as an accessory and is associated with biotite in most places.

CLASSIFICATION: Biotite granodiorite
Johannsen No. 227

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4499 c
Collector. D. H. Rousell

Location. 54° 35' N., 97° 45' W.
Cross Lake, Manitoba
Occurrence. 6" cobble in Cross
Lake group cong.

MEGASCOPIC DESCRIPTION:

Color: f.s. medium dark grey
Grain size: fine, average 0.5 to 1mm
Texture: granitic, faintly foliated

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary):

Anhedral inequigranular. Mortar structure and sutured grain boundaries common. No foliation in thin section.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:		
Plagioclase An 20 68		Carbonate 0.4
Quartz 29		Chlorite 0.4
Biotite 1		Sericite tr
Accessory:		INTRODUCED
Muscovite 0.3		
Apatite 0.4		
Mag.-Il.-Pyrr. 0.4		
Zircon tr		

SPECIAL FEATURES AND INTERPRETATIONS:

1. Plagioclase is strongly altered to sericite. Most grains are rounded and surrounded by finer material.
2. Quartz is slightly strained and occurs in composite aggregates.
3. Biotite occurs in aggregates associated with the opaques and chlorite.
4. Apatite is abundant as an accessory and occurs as stubby euhedrons up to 0.5 mm in length.

CLASSIFICATION: Quartz diorite
Johannsen No. 128

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4500 Ma30-1
Collector. R. A. Burwash

Location. 55°19'N., 97°40'W.
Thicket Portage
Manitoba

Occurrence. gneisses of the pre-Assean Lake group

MEGASCOPIC DESCRIPTION:

Color:f.s. greyish black
Grain size: fine, average about 0.5 mm
Texture: thinly banded gneissic

MICROSCOPIC DESCRIPTION:

Texture and structure (both primary and secondary)

Anhedral inequigranular. Thin section shows microbanding of mafic rich and mafic poor phases. Bands are on the order of 2 mm in thickness.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible percentages estimated)

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Hornblende 46 Plagioclase An 38 31 Pyroxenes 9 Magnetite-Ilmenite 7	Uralite? 3 Carbonate 0.9 Chlorite tr
Accessory:	Biotite 1.6 Apatite 1.6 Sphene tr Zircon tr	INTRODUCED

SPECIAL FEATURES AND INTERPRETATIONS:

1. Hornblende forms the largest grains of the rock and is pleochroic from green to greenish brown. It is typically anhedral and in places, poikiloblastic. The longer grains are sub-oriented with the foliation.
2. Plagioclase is fresh and twinning is not well developed. Some grains show undulatory extinctions and bent twin lamellae.
3. Two pyroxenes are present. Approximately 1/3 is clinopyroxene with a 2V of about 60° and a positive sign. Z inclined to C is 32 degrees. May be diopside. The other pyroxene is hypersthene which has intense pleochroism from pink to green. It is generally fresh except where locally altered to a fibrous moderate birefringent mineral which is probably colorless urallite.
4. Biotite occurs mostly as alteration from hornblende. It is the iron-rich variety and is pleochroic from light tan to reddish brown.
5. Magnetite-ilmenite occurs in discrete grains and minute oriented intergrowths in the hornblende.

CLASSIFICATION: Pyroxene-plagioclase-hornblende gneiss
Hornblende-granulite facies

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No: 4500 Ma31-1
Collector: R. A. Burwash

Location: 55°19'N., 97°40'W.
Thicket Portage
Manitoba

Occurrence: gneisses of the pre-
Assean Lake group

MEGASCOPIC DESCRIPTION:

Color: f.s. blackish red
Grain size: fine, 0.2 to 0.5 mm
Texture: gneissic, thinly banded

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary)

Mostly anhedral granular, lepidoblastic. Granoblastic mosaic of quartz and feldspars inset with microbands of sub-oriented biotite and elongate composite lenses of quartz.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Quartz 40 Plagioclase An 20 36 Microcline 18 Biotite 4.8	Sericite 0.2 Chlorite tr Carbonate tr Iron oxides tr
Accessory:	Mag.-Il. 0.2 Epidote tr Zircon tr Apatite tr	INTRODUCED

SPECIAL FEATURES AND INTERPRETATIONS:

1. The occurrence of the quartz is the most peculiar feature of the rock. In addition to its occurrence as small individual grains in the main portion of the rock, it occurs as very elongate stringers composed of many grains. The lenses are about 1 cm in length and 2 mm in width. They show only slight undulatory extinction. These lenses may represent larger grains that have been sheared out and subsequently recrystallized into a mosaic.
2. Plagioclase is well twinned and slightly to intensely altered.
3. Biotite occurs as elongate cluster parallel to the fabric as imparted by the quartz lenses. Carbonate and opaque minerals are associated with the biotite.

CLASSIFICATION: Biotite-quartz-feldspar gneiss
Almandine-amphibolite facies

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4500 Ma30-2
Collector. R. A. Burwash

Location. 55°19'N., 97°40'W.
Thicket Portage
Manitoba
Occurrence. Diabase dike

MEGASCOPIC DESCRIPTION:

Color:f.s. black
Grain size: fine, average about 0.8 mm
Texture: diabasic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary)

Subhedral diabasic. Subhedral plagioclase lathes have composite and single grains of intersertal pyroxene between them.

Mineralogy (minerals are grouped for interpretation; listed in order of abundances and whenever possible, percentages estimated)

PRIMARY	METAMORPHIC	ALTERATION
Essential:		
Pyroxene 52		
Plagioclase An 49 42		
Hornblende 3.1		
Accessory:		INTRODUCED
Mag.-Il. 1.9		
Quartz 0.3		
Apatite tr		

SPECIAL FEATURES AND INTERPRETATIONS:

1. Plagioclase is fresh, continuously zoned, and well twinned.
2. Two pyroxenes are present but clinopyroxene predominates. Both are fairly fresh but there is some alteration to a fine-grained material which is probably urolite or talc. The hornblende looks primary.

CLASSIFICATION: Diabase
Johannsen No. 3212

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No.: 4500 Jnl0-19
 Collector: R. A. Burwash

Location: 56°43'N., 99°34'W
 Rusty Lake, Manitoba
 Occurrence: Post-Sickle intrusion

MEGASCOPIC DESCRIPTION:

Color: f.s. very light grey
 Grain size: medium
 Texture: granitic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary)

Anhedral equigranular. Mosaic texture formed by anhedral grains.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated)

PRIMARY	METAMORPHIC	ALTERATION
Essential:		
Quartz 33		
Plagioclase An 28 31		
Microcline 28		
Muscovite 7.8		
Accessory:		INTRODUCED
Biotite tr		
Epidote tr		

SPECIAL FEATURES AND INTERPRETATIONS:

1. Muscovite occurs in cluster which in places form a bow-tie structure in which the muscovite flakes more or less radiate from the center.
2. Microcline is slightly perthitic. Grid-iron twinning is well developed.
3. Quartz is somewhat strained.

CLASSIFICATION: Muscovite quartz monzonite
 Johannsen No. 127"

PETROGRAPHER
 Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No.: 4500 Au 8-1
Collector:

Location: 56°38'N., 99°36'W.
Rusty Lake, Manitoba
Occurrence: Pre-Sickle intrusion
(post-Wasekwan)

MEGASCOPIC DESCRIPTION:

Color:f.s. medium dark grey
Grain Size: medium
Texture: gneissic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary)

Anhedral granular. Faint gneissocity evident in thin section.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:		
Hornblende 66		Sericite 2.6
Plagioclase An34-42 26		Carbonate 0.4
Quartz 2.2		Chlorite 0.2
Biotite 2.2		
Accessory:		INTRODUCED
Apatite 0.4		
Sphene 0.2		
Mag.-Il.-Pyrr. tr		

SPECIAL FEATURES AND INTERPRETATIONS:

1. In places plagioclase is somewhat altered to sericite and carbonate. Twinning is moderately well developed. Some grains show zoning.
2. Hornblende is completely fresh. Pleochroic from light green to medium green.
3. Quartz has straight extinction.

CLASSIFICATION: Hybrid hornblende diorite
Johannsen No. 3212

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No: RB-396-2-61
Collector: Fritz Koster

Location: 59°59'N., 109°35'W.
Occurrence: Xenolith in gneissic granite

MEGASCOPIC DESCRIPTION:

Color: f.s. greyish black
Grain size: fine, 0.1 to 1 mm, average about 0.3 mm
Texture: granular

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary):

Anhedral inequigranular. Sutured and ragged grains are common.
Locally poikiloblastic. Some suggestion of nematoblastic texture.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated)

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Plagioclase An 27 55 Hornblende 30 Biotite 10 Quartz 5	Sericite tr
Accessory:	Mag.-Il. tr Sphene tr Apatite tr	INTRODUCED

SPECIAL FEATURES AND INTERPRETATIONS:

1. Hornblende is pleochroic in shades of bluish green. It commonly has ragged edges and is poikilitic in places with numerous inclusions.
2. Plagioclase is moderately to slightly altered to sericite. In most places it is poorly twinned with suggestions of continuous zoning. Some grains show well developed albite and percline twinning. Inclusions of all other minerals occur.
3. Quartz occurs as small single grains but mostly in composite aggregates with relatively straight boundaries. It has undulatory extinction and is locally fractured. Minute inclusions are numerous.

CLASSIFICATION: Biotite-hornblende-plagioclase hornfels
Almandine-amphibolite facies

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4524
Collector. Zell Peterman

Location. 59°29'N., 105°36'W.
Mary Lake, Saskatchewan
Occurrence. cobble in Tazin
conglomerate

MEGASCOPIC DESCRIPTION:

Color: f.s. dark grey
Grain size: fine, average about 0.8 mm
Texture: granitic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary)

Anhedral to subhedral granular. Equil-sized grains form a simple mosaic texture.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated)

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Hornblende 56 Plagioclase An 61 29 Pyroxene (augite?) 13	Sericite tr
Accessory:	Myrmekite? 2 Apatite tr Pyrite tr	INTRODUCED

SPECIAL FEATURES AND INTERPRETATIONS:

1. The plagioclase is very fresh in most places. Twinning according to the albite and pericline laws is well developed. The centers of some grains are slightly altered to sericite. Some of the grains show slight undulatory extinction and twin lamellae are bent. There is continuous zoning from An 61 to An 53.
2. Hornblende is quite fresh and pleochroic from green to brownish green.
3. Pyroxene is mostly fresh. Some of the hornblende may have altered from pyroxene. Some grains of pyroxene appear to grade into hornblende. Others show sharp discrete boundaries.
4. The few grains of pyrite have a halo of iron oxide.
5. Myrmekite-like intergrowths occur in places, mainly near the contacts of the mafic minerals and plagioclase. The intergrowths seem to have invaded the plagioclase.

CLASSIFICATION: Pyroxene-hornblende-labradorite granulite PETROGRAPHER
Granulite facies Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4683 Au22-3

Collector: R. A. Burwash and Z. Peterman

Location: 54°47'N., 101°50'W.

Flin Flon, Manitoba

Occurrence: Mafic phase of
Cliff Lake "quartz-
eye" granite (pre-
Missi)

MEGASCOPIC DESCRIPTION:

Color: f.s. medium grey

Grain size: fine, 0.8 to 1.0 mm

Texture: dioritic

MICROSCOPIC DESCRIPTION:

Texture and structure: (primary and secondary)

Subhedral granular. Essential minerals are approximately equigrained. Fracturing has occurred and the fractures filled with epidote and carbonate.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:		
Plagioclase An 30 65		Epidote tr
Hornblende 20		Carbonate tr
Quartz 5		Chlorite tr
		Leucozene tr
Accessory:		INTRODUCED
Sphene tr		Epidote and carbonate
Pyrite tr		in veinlets.

SPECIAL FEATURES AND INTERPRETATIONS:

*Mode visually estimated.

1. Hornblende is fresh except where fractured along which chlorite has developed.
2. Plagioclase has been considerably altered to epidote and An content may have originally been much higher than An 30.
3. Evidence of dynamic metamorphic is indicated by fractures which have been filled with a mixture of epidote and carbonate. Some individual grains of plagioclase, hornblende, and quartz are locally fractured. Rock has not been at all sheared.

CLASSIFICATION: Hornblende quartz diorite
Johannsen No. 2212

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4683 Au 23-2

Collectors: R. A. Burwash and Z. Peterman

Location: 56°44'N., 101°12'W.

Lynn Lake, Manitoba

Occurrence: Pre-Sickle intrusion

MEGASCOPIC DESCRIPTION:

Color: medium grey

Grain Size: fine, 0.05 to 1 mm

Texture: gneissic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary)

Anhedral inequigranular. Sutured grain boundaries are common.

Hornblende is poikilitic with very ragged edges.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:		
Quartz)		Sericite tr
Plagioclase) 80		Epidote tr
		Carbonate tr
		Chlorite tr
Hornblende 20		Iron oxide tr
Accessory:		INTRODUCED
Mag.-Il. tr		
Apatite tr		
Zircon tr		
Biotite tr		

SPECIAL FEATURES AND INTERPRETATIONS:

*Mode visually estimated.

1. Hornblende is fresh; pleochroic from bluish green through brownish green to dark green; poikilitic with numerous small rounded inclusions of quartz or feldspar.

2. Quartz and feldspar occurs as composite grains with sutured boundaries and as a finer grained mass throughout the rock. The plagioclase is very poorly twinned and has a patchy extinction. Interference figures are very poor. In places it contains numerous inclusions some of which are wormy intergrowths. Composition is oligoclase or andesine based on refractive indices.

3. Rock has undergone considerably alteration. Dynamic metamorphism may have formed the finer grained material; but appears to have been partially or completely recrystallized at a later time.

CLASSIFICATION: Hornblende (meta-) quartz diorite
Johannsen No. 2212

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4683 Au 23-3

Collectors: R. A. Burwash and Z. Peterman

Location: 56°44'N., 101°12'W

Lynn Lake, Manitoba

Occurrence: cobble in
Sickle conglomerate

MEGASCOPIC DESCRIPTION:

Color: f.s. light grey

Grain size: fine to medium, 0.05 to 2 mm

Texture: gneissic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary):

Anhedral inequigranular (hiatal). Large grains of dominately quartz and feldspar occur in a fine grained mass of quartz and feldspar. Sutured grain boundaries common. Much evidence of cataclasis.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY		METAMORPHIC	ALTERATION	
Essential:			Epidote	tr
Plagioclase	20		Sericite	tr
Quartz	15		Chlorite	tr
Biotite	10		Carbonate	tr
Groundmass	55			
Accessory:			INTRODUCED	
Zircon (metamict)	tr			
Sphene	tr			
Mag.-Il.	tr			
Apatite	tr			

SPECIAL FEATURES AND INTERPRETATIONS:

*Mode visually estimated.

1. Rock is similar to 4683 Au 23-2 except biotite is main mafic phase.
2. Large single and composite grains of quartz are markedly strained and show sutured boundaries. Large recognizable plagioclase grains are considerably altered and composition determination is impossible.
3. Groundmass consists of fine-grained quartz and feldspar with some biotite. It was probably formed by cataclasis.

CLASSIFICATION: Biotite (meta-) quartz diorite

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4683 Au 23-5

Collector: R. A. Burwash and Z. Peterman

Location: 56°43'N., 101°12'W.

Lynn Lake, Manitoba

Occurrence: Wasekwan volcanics

MEGASCOPIC DESCRIPTION:

Color: f.s. greyish black

Grain size: fine, average is about 0.5 mm

Texture: schistose

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary):

Subhedral nematoblastic, lepidoblastic, and poikiloblastic. Biotite. Hornblende and biotite show well developed preferred orientations. Quartz and feldspar are definitely finer grained than hornblende and biotite.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Hornblende 50 Biotite 15 Quartz) 35 Feldspar)	Carbonate tr Chlorite tr
Accessory:	Pyrite tr Zircon tr Epidote tr Sphene tr	INTRODUCED Chlorite in cross-cutting veinlet.

SPECIAL FEATURES AND INTERPRETATIONS:

1. It is impossible to differentiate between the quartz and feldspar because of the fine grain size and poorly twinned condition of the feldspar. There does not appear to be any K-feldspar present and plagioclase is probably oligoclase or andesine as shown by refractive indices.

2. Hornblende shows well developed sieve structure with numerous rounded inclusions of quartz and feldspar. In places these inclusions are aligned in rows parallel to the foliation regardless of the orientation of the hornblende. Hornblende is completely fresh and pleochroic in shades of bluish green.

3. Biotite is reddish brown and in places appears to be the alteration product of hornblende.

CLASSIFICATION: Biotite-hornblende schist
Almandine-amphibolite facies

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4684-6
Collector. Zell Peterman

Location. 47°55'N., 108°34'W.
Little Rocky Mountains
Montana
Occurrence: Pre-Beltian gneisses

MEGASCOPIC DESCRIPTION:

Color: f.s. dark grey
Grain size: fine grained groundmass with large porphyroblasts
Texture: porphyroblastic, schistose

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary)

Anhedral to subhedral lepidoblastic. Somewhat sheared. Porphyroblasts not shown by thin section.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Quartz 32 Plagioclase An 26 35 Biotite 17 Microcline 8	Chlorite 4 Carbonate 2 Iron oxides 1 Leucoxene 1 Sericite 1
Accessory:	Zircon tr Apatite tr Sphene tr	INTRODUCED

SPECIAL FEATURES AND INTERPRETATIONS:

1. Plagioclase is locally altered but mostly fresh.
2. Quartz in places occurs as elongate composite lenses oriented in the direction of the foliation.
3. In places chlorite and carbonate are associated in aggregates. One mass of chlorite suggests alteration from hornblende because of the pattern formed.
4. Zircon is fractured and metamict and apatite is well rounded.

CLASSIFICATION: Porphyroblastic biotite-quartz-feldspar
schist
Almandine-amphibolite facies

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4684-7
Collector. Zell Peterman

Location. 47°55'N., 108°34'W.
Little Rocky Mountains
Montana
Occurrence: Pre-Beltian gneisses

MEGASCOPIC DESCRIPTION:

Color: f.s. black
Grain size: fine, 0.5 to 1 mm
Texture: gneissic or foliated

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary)

Anhedral to subhedral granular and nematoblastic, poikiloblastic.
Sutured grain boundaries and minor fractures.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Hornblende 67 Plagioclase An 28 18 Quartz 12	Carbonate 0.2 Sericite tr Leucoxene tr
Accessory:	Sphene 2.0 Microcline 0.4 Apatite tr Epidote tr Mag.-Il. tr Zircon tr	INTRODUCED

SPECIAL FEATURES AND INTERPRETATIONS:

1. Hornblende is poikiloblastic with well developed sieve texture. It includes all of the other minerals but mainly quartz and sphene.
2. Plagioclase is well twinned and completely fresh.
3. Quartz occurs small rounded grains in hornblende and as composit mosaics. It is relatively unstrained.
4. Sphene is abundant as an accessory and is usually well rounded.
5. A few zircon are present and these are brown and metamict.
6. Two small fractures occur in the thin section along which crushing has occurred and carbonate is localized along these.

CLASSIFICATION: Quartz-feldspar-hornblende gneiss or
amphibolite
Almandine-amphibolite facies

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4685-10
Collector. Zell Peterman

Location. 47°01'N., 110°46'W.
Little Belt Mountains
Montana
Occurrence. Pre-Beltian gneisses

MEGASCOPIC DESCRIPTION:

Color:f.s. dark grey
Grain size: fine, average about 0.3 mm
Texture: thinly banded gneissic

MICROSCOPIC DESCRIPTION:

Texture and structure (both primary and secondary)

Anhedral inequigranular. Foliation and banding well shown in thin section.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:	Plagioclase An 33 43 Quartz 31 Hornblende 13 Biotite 12	Sericite tr
Accessory:	Apatite 0.6 Mag.-Il. 0.2 Zircon tr	INTRODUCED

SPECIAL FEATURES AND INTERPRETATION:

1. most of the plagioclase is very fresh. The occasional grain is moderately altered to sericite.
2. Quartz is moderately strained and in places contains numerous inclusions.
3. Only one zircon was noted in thin section. A zircon separate was obtained from the heavies. Most are zoned and rounded and probably hyacinth variety.
4. Biotite is pleochroic from light tan to dark reddish brown.
5. Hornblende is completely fresh and pleochroic from dark green to brown.

CLASSIFICATION: Biotite-hornblende-quartz-andesine gneiss
Almandine-amphibolite facies

PETROGRAPHER
Zell Peterman

PETROGRAPHIC DESCRIPTION

FIELD DATA:

Sample No. 4686
Collector: Z. Peterman

Location: 59°21'N., 105°41'W.
Stony Rapids, Sask.
Occurrence: Post-Tazin intrusion
(stock)

MEGASCOPIC DESCRIPTION:

Color: brownish grey
Grain size: fine, 0.1 to 1mm
Texture: phaneritic, porphyritic

MICROSCOPIC DESCRIPTION:

Texture and structure (primary and secondary):

No phenocrysts are evident in thin section.
Anhedral, markedly inequigranular. Rock has been sheared and fractured.
Sutured grain boundaries are common.

Mineralogy (minerals are grouped for interpretation; listed in order of abundance; and whenever possible, percentages estimated):

PRIMARY	METAMORPHIC	ALTERATION
Essential:		
Plagioclase 60		Epidote 5
Biotite 20		Sericite tr
Quartz 15		Chlorite tr
		Carbonate tr
Accessory:		INTRODUCED
Muscovite tr		
Apatite tr		
Mag.-Il. tr		
Zircon tr		
Sphene tr		

SPECIAL FEATURES AND INTERPRETATIONS:

*Mode visually estimated.

1. Plagioclase is very poorly twinned and moderately to intensely altered to sericite and epidote. Probably oligoclase in composition.
 2. Quartz and biotite are localized in separate concentrated masses. Some areas consist completely of fine-grained anhedral quartz mosaics. Other places are fibrous aggregates of biotite.
 3. Epidote occurs dispersed throughout the slide as small subhedral to euhedral grains.
 4. Rock appears to have undergone moderate shearing with subsequent annealing by a later thermal event. This is not evident in hand specimen as rock appears to be a relatively unaltered porphyry.
- CLASSIFICATION: Porphyritic biotite granite
Johannsen No. 2212

PETROGRAPHER
Zell Peterman

APPENDIX C

Basic Data for Map Point Counts

Map Unit	Points	Percent	Map Unit	Points	Percent
Stanley (Mawdsley and Grout, 1951):			Settee Lake (Budding, 1955):		
1	3	0.3	1	106	20.0
2	135	14.1	2	261	49.1
3	8	0.8	3	18	3.4
4	415	43.5	4	17	3.2
5	0	0.0	5	4	0.8
6	391	41.0	6	36	6.8
7	3	0.3	7	89	16.7
Totals	955	100.0	Totals	531	100.0
Lakes	355		Lakes	133	
Cover	17		-----		
-----			Hanson Lake (Byers, 1957):		
Deschambault Lake (Kirkland, 1958):			1	114	19.2
1	1	0.2	2	12	2.0
2	161	30.9	3	8	1.3
3	40	7.7	4	33	5.7
4	93	17.8	5	75	12.6
5	3	0.6	6	14	2.4
6	164	31.5	7	177	29.8
7	59	11.3	8	21	3.5
Totals	521	100.0	9	137	23.1
Lakes	153		10	2	0.3
			Totals	593	100.0
			Paleozoics	374	
			Lakes	394	

Map Unit	Points	Percent	Map Unit	Points	Percent
Goldfields-Martin Lake (Christie, 1953):			Charlebois Lake (Mawdsley, 1957a):		
1	21	1.3	1	51	7.4
2	2	0.1	2	21	3.0
3	141	8.9	3	50	7.2
3a	43	2.7	4	14	2.0
3b	22	1.4	5	29	4.2
4	215	13.6	6	5	0.7
4a	25	1.6	7	485	70.1
5	867	54.8	8	37	5.4
5a	16	1.0	Totals	692	100.0
5b	0	0.0	Cover	40	
6	76	4.8	Lakes	135	
7	85	5.4	-----		
8	14	0.9	Middle Foster Lake (Mawdsley, 1957b)		
9	5	0.3	1	401	41.6
Totals	1581	100.0	2	35	3.6
-----			3	9	0.9
Crackingstone (Fraser, 1960):			4	64	6.7
1	22	13.3	5	232	24.1
2	73	44.2	6	139	14.5
3	35	21.2	7	36	3.8
4	10	6.1	8	43	4.5
5	1	0.6	9	3	0.3
6	9	5.5	Totals	962	100.0
A	12	7.3	Cover	194	
B	3	1.8	Lakes	391	
Totals	165	100.0			
Lakes	449				

Map Unit	Points	Percent	Map Unit	Points	Percent
Waddy Lake (Byers, 1949):			Reindeer River (Budding and Kirkland, 1956):		
1	305	11.7	1	197	20.5
2	929	35.6	2	210	21.8
3	73	2.8	3	64	6.7
4	16	0.6	4	25	2.6
5	6	0.2	5	53	5.5
6	4	0.1	6	412	42.9
7	39	1.5	Totals	961	100.0
8	1239	47.5	Cover	4	
Totals	2611	100.0	Unexplored	204	
Lakes	539		Lakes	430	
Unexplored	32		-----		
-----			Manawan Lake (Kirkland, 1957):		
Windrum Lake (Miller, 1949):			1	35	6.2
1	584	33.8	2	8	1.4
2	8	0.5	3	11	1.9
3	17	1.0	4	36	6.4
4	68	3.9	5	52	9.2
5	138	8.0	6	17	3.0
6	45	2.6	7	36	6.4
7	110	6.4	8	4	0.7
8	757	43.8	9	366	64.8
Totals	1727	100.0	Totals	565	100.0
Till	235		Cover	22	
Swamp	377		Lakes	140	
Lakes	231				

Map Unit	Points	Percent	Map Unit	Points	Percent
Mari Lake (Cheesman, 1956):			Amisk-Wildnest Lakes (Byers and Dahlstrom, 1954):		
1	20	3.4	1	1306	16.7
2	41	7.1	2	525	6.7
3	379	65.4	3	518	6.6
4	50	8.6	4	234	3.0
5	10	1.7	5	32	0.4
6	76	13.1	6	172	2.2
7	4	0.7	7	373	4.8
Totals	580	100.0	8	386	4.9
Lakes and swamps	117		9	1001	12.8
			10	31	0.4
			11	293	3.7
			12	23	0.3
			13	156	2.0
			14	2319	29.6
			15	97	1.2
			16	72	0.9
			17	305	3.9
			Totals	7843	100.1
			Paleozoics	407	
			Lakes	3233	

Map Unit	Points	Percent
----------	--------	---------

Lynn Lake (Milligan, 1960):

1	4	0.1
2	216	3.8
3	74	1.3
4	63	1.1
5	851	14.9
6	15	0.3
7	111	1.9
8	2	tr
9	186	3.3
10	215	3.8
11	1333	23.4
12	212	3.7
13	77	1.3
14	706	12.4
15	0	0.0
16	28	0.5
17	420	7.4
18	418	7.3
19	36	0.6
20	98	1.7
21	19	0.3
22	0	0.0
23	186	3.3
24	102	1.8
25	339	5.9
Totals	5711	100.1
Lakes	949	
Unexplored	606	

STRUCTURE CONTOUR MAP OF THE PRECAMBRIAN SURFACE OF THE WESTERN CANADA SEDIMENTARY BASIN

0 100 200
SCALE OF MILES

○ 42 Sample Location and Index Number

Contour Intervals:

Canada 500'

U.S.A. 1000' and 2000'

ROCK TYPES

- Sedimentary and metasedimentary
- Volcanic and metavolcanic
- Silicic to intermediate Plutonic
- Igneous
- Metamorphic
- Mafic Plutonic
- Igneous
- Metamorphic

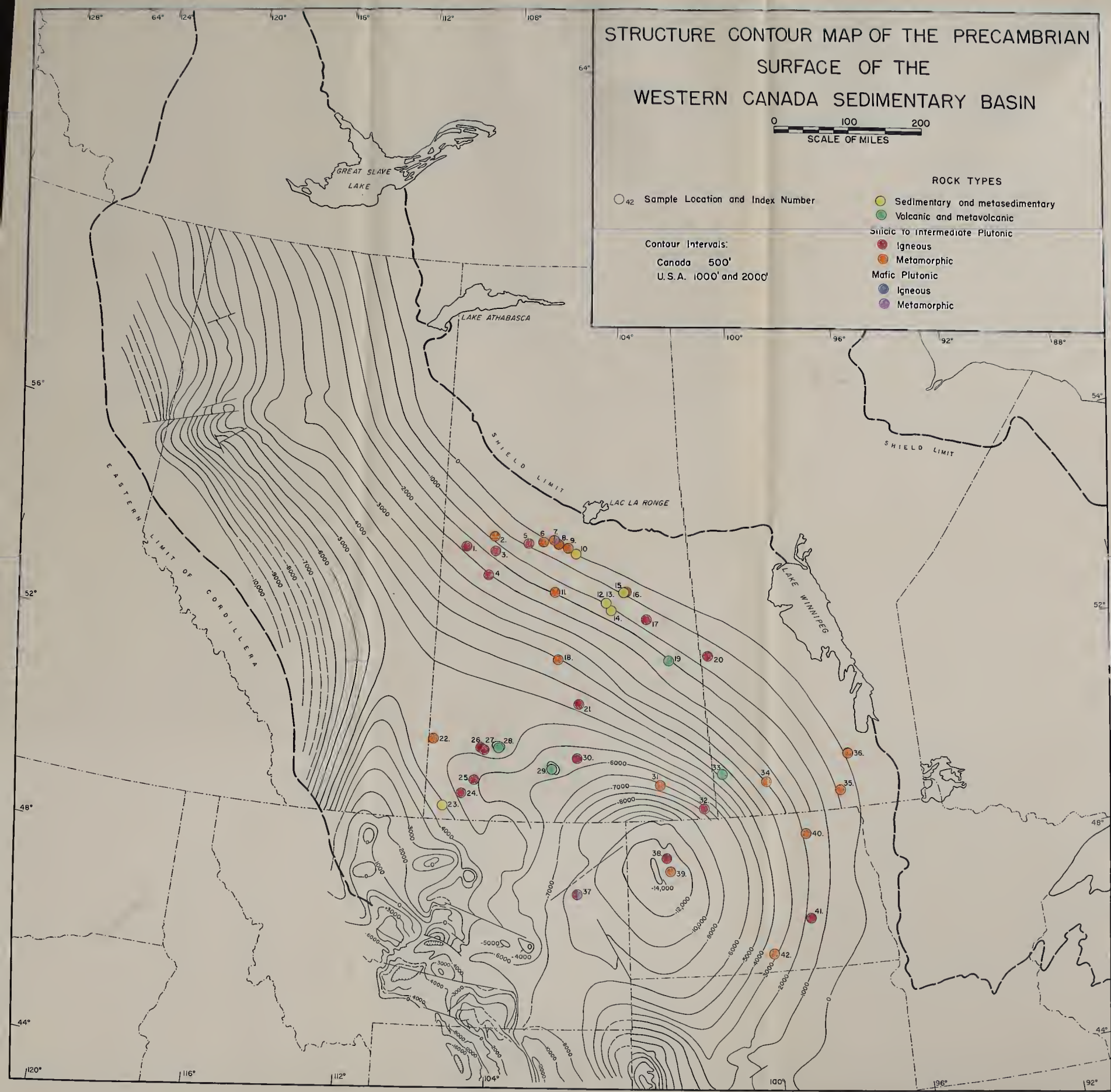


Figure 12

A horizontal scale bar with alternating black and white segments. It is marked with the numbers 0, 100, and 200. Below the bar, the text "SCALE OF MILES" is printed.



Figure 13

GEOLOGIC DIVISIONS

- Province Boundaries
- Subprovince Boundaries

PROVINCES

- Bear
- Slave
- Churchill
- Superior

SUBPROVINCES

- I. East Arm
- II. Nanache
- III. Athabasca
- IV. Rankin
- V. Thelan
- VI. Athabasca Plain

K-Ar AND Rb-Sr DATES WESTERN CANADA

0 100 200

SCALE OF MILES

- Basement Samples
- △ Outcrop Samples

2.40 K-Ar Date (by)

1.63 Rb-Sr Date (by)

SOURCE OF DATA

- Present Investigation (Index Numbers)
- △ Lawdon et al (1960, 1961)
- ⊙ Burwash et al (1962)
- △ Moore et al (1960)
- △ Gast et al (1958)
- △ Hayden and Wehrenberg (1960)
- △ Aldrich et al (1958)
- △ Galdich et al (1961)
- △ Galfrey and Baadsgaard (1962)
- △ Burwash and Baadsgaard (1962)
- △ Giletti and Gast (1961)

MINERALS DATED

- m Muscovite
- h Hornblende
- p Pyroxene
- i Lepidolite
- mi Microcline

No letter by date indicates biotite except for average values

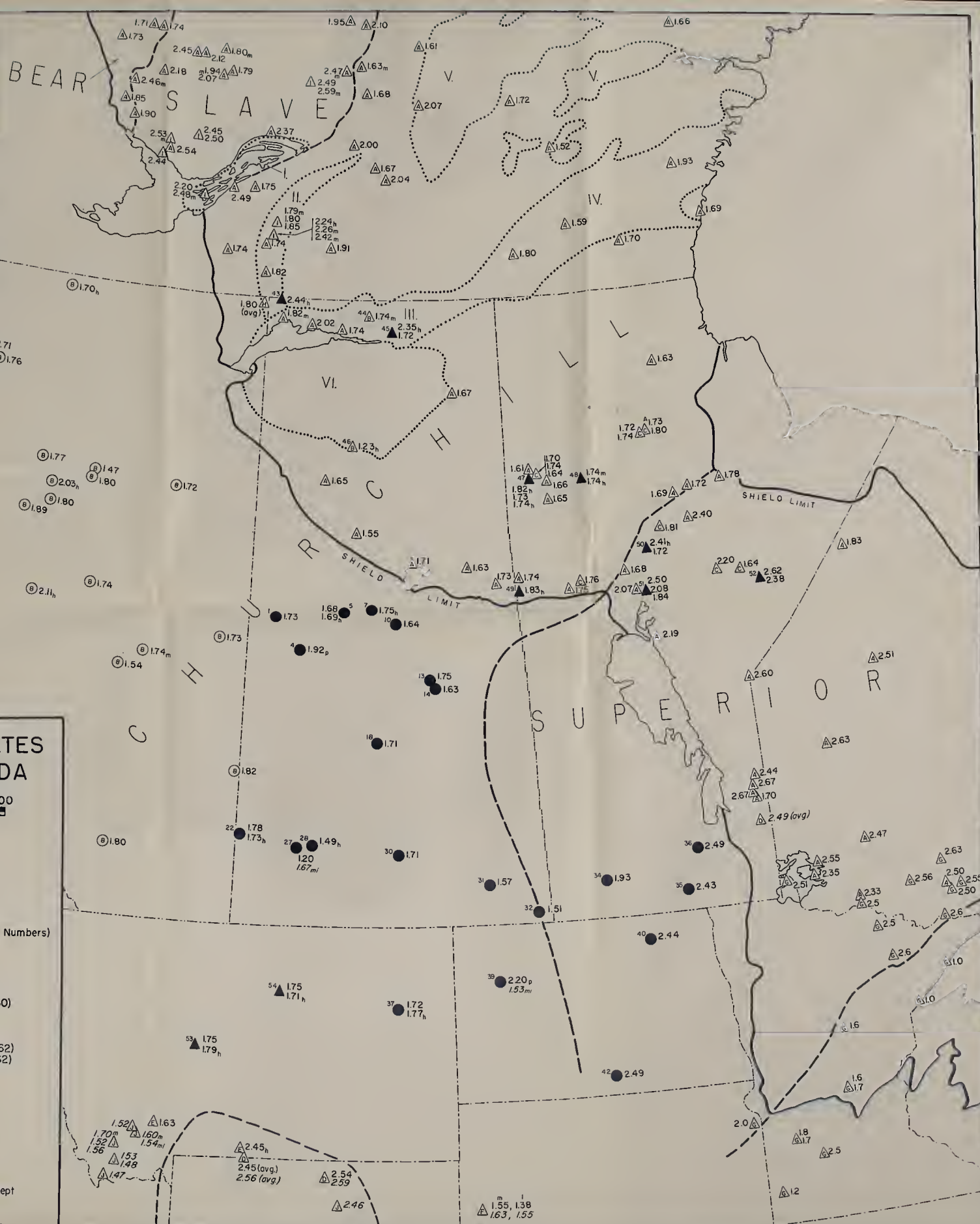


Figure 20

B29804